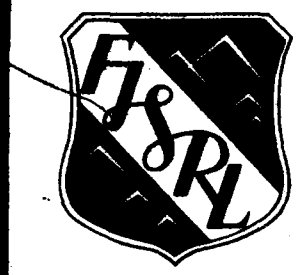

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FRANK J. SEILER RESEARCH LABORATORY

FJSRL TECHNICAL REPORT - 76-0008
SEPTEMBER 1976

SOLAR HEATING RETROFIT OF MILITARY FAMILY HOUSING

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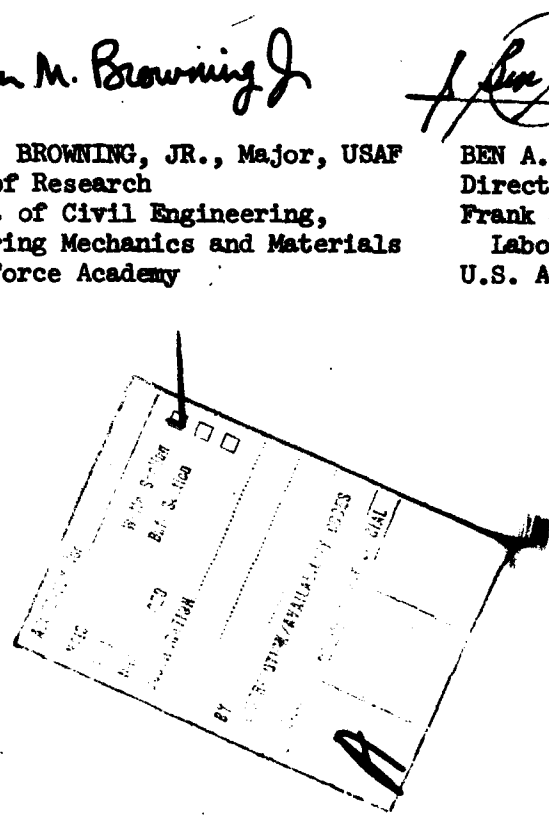

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SOLAR HEATING RETROFIT

OF

MILITARY FAMILY HOUSING

by

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This interim technical report describes the programming, facility, acquisition and initial performance of the first retrofit constructed solar-heated facility in the United States Air Force, the Solar Test House at the United States Air Force Academy.

The Air Force civil engineer is responsible today for operating and maintaining approximately 150,000 units of military family housing. As is the case

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in the private sector, the Air Force civil engineer is experiencing higher operating and maintenance costs due to inflation. Just recently, operating costs have begun to exceed maintenance costs. Higher energy related utility costs are believed responsible for this.

Accordingly, Air Force civil engineers are interested in investigating the use of alternate energy schemes such as solar energy for its real property, not only in response to inflation in energy costs but also in response to energy crisis scenarios for a number of reasons which include: providing a mechanism to help offset rising utility costs; providing a mechanism to help guarantee mission continuation at installations that have their normal sources of conventional fossil fuels curtailed; and contributing to the national objective of energy self-sufficiency.

Significant work in solar energy is currently on-going in the private sector. This work effort involves the application of solar energy for space heating, domestic hot water heating and air conditioning. However, this work is predominantly in the new construction category. Because the Air Force's real property assets are largely fixed and because the engineering involved in new construction differs from that involved in retrofit construction, the solar energy work being done in the private sector may not be readily applicable to the Air Force. Accordingly, this project addresses the problem of solar energy facility retrofit with the objectives of developing baseline design criteria, obtaining design, construction and operation and maintenance experience, and obtaining sound cost data in order to support future Air Force solar energy programs.

FOREWORD

This report was prepared by members of the Department of Civil Engineering, Engineering Mechanics and Materials (DFCEM), and the Department of Electrical Engineering of the Faculty (DFEE), and the Office of the Deputy Chief of Staff for Civil Engineering (DCSDE), United States Air Force Academy, Colorado. The work was initiated under Frank J. Seiler Research Laboratory Project No. 7903, Task 7903-03 and Work Unit No. 7903-03-75. The project investigators were Major Marshall W. Nay, Jr., Captain Jon M. Davis, Captain Roy L. Schmiesing, and First Lieutenant William A. Tolbert. Project Co-directors were Colonel Wallace E. Fluhr and Colonel Donald R. Reeves. Funding support from the Air Force Aero Propulsion Laboratory (AFAPL) during the acquisition phase under Program Element Project PE 62203F and from the Air Force Civil Engineering Center (AFCEC) during the test and evaluation phase under Program Element Projects 63723F and 64708F are acknowledged.

This report covers work accomplished from April 1973 to June 1976. This manuscript was released by the authors for publication in September 1976.

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TABLE OF CONTENTS

CHAPTER	TITLE	PAGE NO.
1	INTRODUCTION AND OBJECTIVES	1-1
	1.1 Introduction	1-1
	1.2 Project Objectives	1-2
2	PROJECT OVERVIEW	2-1
	2.1 Problem Addressed	2-1
	2.2 Project Scope of Work	2-2
3	PROGRAMMING	3-1
	3.1 Concept Development	3-1
	3.2 Project Establishment and Funding	3-7
	3.3 Project Execution	3-10
4	CONTRACTING	4-1
	4.1 Scope of Work	4-1
	4.2 Method of Accomplishment	4-1
	4.3 Contract Negotiations	4-3
	4.4 Cost Summary	4-4
	4.5 Government/Contractor Relations	4-4
	4.6 Summary	4-5
5	SOLAR TEST HOUSE FACILITIES ACQUISITION	5-1
	5.1 Quarters Description and Selection	5-1
	5.2 Heating Demand	5-6
	5.3 Ground and Roof Array	5-7
	5.4 Solar Collectors	5-24
	5.5 Thermal Storage Tank	5-32
	5.6 Supporting Mechanical Equipment	5-45
6	INSTRUMENTATION AND CONTROL SYSTEM	6-1
	6.1 Introduction	6-1
	6.2 Solar Heating System Software	6-3
	6.3 Solar Heating System Hardware	6-8
	6.4 General Considerations for Signal	6-17

CHAPTER	TITLE	PAGE NO.
6	INSTRUMENTATION AND CONTROL SYSTEM (cont)	
	6.5 Solar Radiation	6-19
	6.6 Other Meteorological Monitoring Equipment	6-21
	6.7 Temperature Sensors	6-23
	6.8 Flow Measurement	6-27
	6.9 Other Instrumentation	6-29
7	TEST AND EVALUATION DATA AND RESULTS	7-1
	7.1 Introduction	7-1
	7.2 Solar Energy Available	7-6
	7.3 Solar Energy Collected and Stored	7-9
	7.4 House Heating Demand	7-22
	7.5 Domestic Hot Water Heating Demand	7-26
	7.6 System Modeling Techniques and Results	7-28
8	CONCLUSIONS AND RECOMMENDATIONS	8-1
	8.1 General	8-1
	8.2 Specific Project Conclusions	8-3
	8.3 Specific Recommendations for Continuing Project Work	8-5
	8.4 Project Related Cadet Education Program	8-9
	BIBLIOGRAPHY	9-1
	APPENDIX	
	A. Degree Days at the United States Air Force Academy	A-1
	B. Calculated Heat Loss for Type 12 Quarters at the United States Air Force Academy	B-1
	C. USAFA Solar Test House As-Build Construction Drawings	C-1
	D. Instrumentation and Control System Flow Charts, Block Diagrams and Circuit Schematic Diagrams	D-1
	E. Test and Evaluation Computer Programs	E-1
	F. Solar Energy System Tabularized Performance Data Summary (December 1975 to April 1976)	F-1
	G. Selected Solar Energy System Computer Acquired Performance Plots	G-1
	H. Project Cost Summary for Acquisition Phase	H-1

LIST OF FIGURES

FIGURE	TITLE	PAGE NO.
1.1	USAFA Solar Test House	1-1
2.1	Solar Collectors on the Ground Array	2-4
5.1	Type 12 Quarters Floor Plan	5-4
5.2	USAFA Solar Test House Elevation Views	5-5
5.3	Ground Array Construction Details	5-9
5.4	Ground Array Saddle Details	5-10
5.5	Ground Array Footing Detail	5-11
5.6	Ground Array Saddle Photograph	5-12
5.7	Ground Array Footing Photograph	5-12
5.8	Ground Array Under Construction	5-13
5.9	Ground Array Ready for the Collectors	5-14
5.10	Ground Array Completed	5-15
5.11	Ground Array Shadowing	5-16
5.12a	Roof Array Anchoring Detail	5-18
5.12b	Roof Prepared for Parasite Truss	5-19
5.12c	Parasite Truss Installed	5-19
5.13	Roof Array Completed	5-17
5.14	Ground Array Snow Loading	5-20
5.15	Roof Array Snow Loading Sequence	5-22
5.16	Roof Array Ice Cover	5-23
5.17	Details of Modular Solar Collectors	5-28
5.18	Thermal Storage Tank Details	5-33
5.19	Thermal Storage Tank Being Lowered into Position	5-35
5.20	Thermal Storage Tank Cover Being Installed	5-35
5.21	Thermal Storage Tank Manhole Being Lowered into Position	5-36
5.22	Plumbing Lines Being Installed on Thermal Storage Tank	5-36

FIGURE	TITLE	PAGE NO.
5.23	Changes in Depth of Water in Thermal Storage Tank (November 1975)	5-37
5.24	Changes in Depth of Water in Thermal Storage Tank (December 1975)	5-38
5.25	Pumping Out the Thermal Storage Tank	5-39
5.26	Model of Thermal Storage Tank	5-42
5.27	Thermal Stress Cracking Pattern	5-43
5.28	Thermal Storage Tank Heat Exchanger	5-46
5.29	Furnace Supply Air Plenum Heat Exchanger	5-46
5.30	Solar Energy System Mechanical Equipment	5-47
5.31	Modulating Flow Control Valve	5-48
6.1	Control Algorithm - Arrays	6-5
6.2	Control Algorithm - Heat Coil	6-6
6.3	Control Algorithm - Task Scheduler	6-7
6.4	ICS Hardware in Mechanical Room	6-8
6.5	Digitizer Card	6-10
6.6	Power Control Box with Microcomputer Controlled Solid State Relays	6-10
6.7	Top, Rear View of Microcomputer Chassis Rack Showing Digital Clock and Sensor Readout Units	6-11
6.8	Front View of Microcomputer Chasis Rack with Cover Removed Showing the Analog Multiplexer, Calibrator, Controller and Power Supplies	6-11
6.9	Rear View of Microcomputer	6-12
6.10	Analog Multiplexer	6-12
6.11	Sensor Termination Panel	6-13
6.12	Remote House Controller (Solar Control House)	6-13
6.13	Status Display Console	6-14
6.14	Teletype	6-15
6.15	Pyranometer	6-20
6.16	AN/TMQ-15 Wind Measuring Set	6-22
6.17	AN/TMQ-20 Temperature and Dew-Point Measuring Set	6-22

FIGURE	TITLE	PAGE NO.
6.18	Temperature Transducers	6-23
6.19	Wet Sensors Installed in Domestic Hot Water Preheat Coil	6-25
6.20	Wet Sensors Installed in Roof Array Header Pipes	6-26
6.21	Fluid Flow Meter	6-28
6.22	Natural Gas Meter	6-29
6.23	Electrical Meters in Solar Test House	6-30
6.24	Thermal Storage Tank Depth Meter	6-31
7.1	Standard Daily Summary of Analysis Program	7-5
7.2	Average Monthly Solar Radiation	7-11
7.3	Slope - Sun Altitude Relationship	7-12
7.4	Relationship Between Sun Altitude and Degree Days with Time at USAFA	7-14
7.5	Collection and Storage Control Algorithm Supporting Mechanical Components	7-18

LIST OF TABLES

TABLE	TITLE	PAGE NO.
5.1	Comparison of Modular Solar Collector Features	5-26
5.2	Summary of Water Sampling Results of the Thermal Storage Tank	5-41
7.1	ICS Recorded Data Points at the USAFA Solar Test House	7-3
7.2	Solar Test House Data Analysis Program Calculated Data Points	7-4
7.3	Average Monthly Solar Radiation Values	7-10
7.4	Slope - Sun Altitude Relationship	7-12
7.5	Comparison of Working Fluids for Heat Transfer	7-16

CHAPTER 1

INTRODUCTION AND OBJECTIVES

1.1 Introduction

This interim technical report describes the programming, facility acquisition and initial performance of the first retrofit constructed solar-heated facility in the United States Air Force, the Solar Test House at the United States Air Force Academy (see Figure 1.1 below).

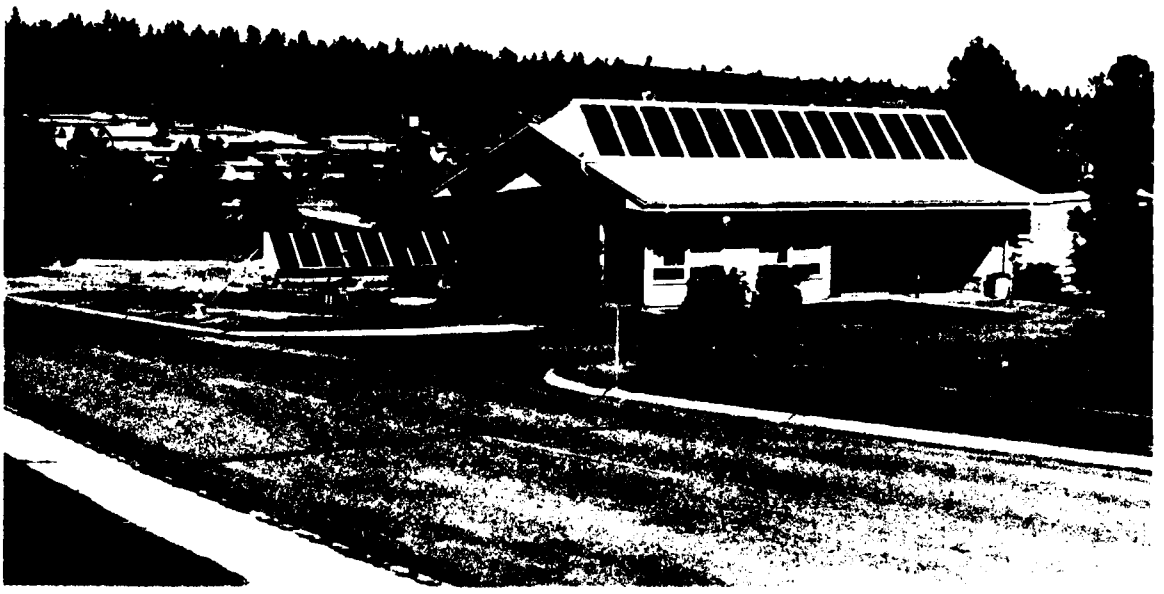

Figure 1.1 USAFA Solar Test House

This project, which to date is the major part of the Air Force Academy Solar Energy Program, has been accomplished using the Air Force Academy's own engineering personnel from its various mission elements in an integrated manner with the administrative assistance of personnel from the Frank J. Seiler Laboratory of the Air Force Systems Command, which is an Air Force Academy tenant. This project represents a joint venture between the United States Air Force Academy and the Air Force Systems Command. Specifically, within the Air Force Systems Command, the Air Force Aero Propulsion Laboratory provided the funds for the acquisition phase, and the Air Force Civil Engineering Center is now providing the funds for test and evaluation. In addition, the Air Weather Service of the Military Airlift Command has supported the project by providing a meteorological monitoring system located at the site. Because this project is the first experimental real property solar energy heating project to be done, not only in the Air Force but also in the Department of Defense, it is hoped that this report will provide useful information to support future Air Force/Department of Defense projects.

1.2 Project Objectives

The objectives of this project have been:

a. to develop baseline design criteria to support future Air Force Solar Energy Programs;

b. to obtain sound design, construction and operations

and maintenance experience in real property-oriented solar energy systems;

c. to obtain sound cost data on such solar energy systems upon which future economic effectiveness models may be based.

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CHAPTER 2

PROJECT OVERVIEW

2.1 Problem Addressed

This project addresses the problem concerned with the spiraling cost and dwindling supply of fossil fuels, as manifested by "energy crisis" scenarios. Accordingly, the Air Force needs to consider applying alternate energy schemes to its own special real property needs for the following reasons:

a. to provide a mechanism to help offset rising utility costs associated with the inflationary trend that has been characteristic of conventional fossil fuels;

b. to provide a mechanism to help guarantee mission continuation at installations that have their normal sources of conventional fossil fuels curtailed;

c. to contribute to the national objective of energy self-sufficiency.

This work was done at the Air Force Academy for the following reasons:

a. the Air Force Academy's climate makes it very well suited for an experimental solar energy facility because of its record of long periods of continuous high quality sunlight;

b. the facilities at the Air Force Academy are representative of what can be expected in the composition of the

real property base of Air Force installations in the future;

c. the multidisciplinary faculty found at the Air Force Academy provides the broad technical base necessary for solar energy research;

d. it is Air Force Academy policy that cadets will participate in research projects such as are found in the Solar Energy Program and as a result, a unique opportunity for technology transfers to the operating Air Force is provided;

e. the Air Force Academy has established base needs that dictate the future development of an alternate energy source. During the winter of 1972, the Air Force Academy's interruptible natural gas supply was curtailed for 171 days (December 1972 to May 1973) due to a shortage of natural gas in the area. Fortunately, the Air Force Academy was able to switch over to fuel oil and continue to operate. Nevertheless, at the end of the fiscal year, the effect of this operation was an additional cost of $454,000 required to operate during the curtailment. It was this specific experience, more than anything else, that acted as the catalyst for the present project.

2.2 Project Scope of Work

The project scope of work involved constructing an applied research and development laboratory for solar energy applications. This was accomplished by retrofitting an existing single-family military housing unit at the Air Force Academy with commercial flat

plate solar collectors. The primary purpose was space heating and the secondary purpose was domestic hot water preheating.

The solar energy system developed is unique in that the 28 commercially-manufactured solar collectors are mounted in two separate arrays. Half of the collectors (273 square feet, 14 solar collectors) are mounted in an array on the roof at a fixed angle of 52° from the horizontal, and the other half are mounted on a ground array directly behind the house. The ground array is so constructed that the horizontal angle of the collectors may be set at 45°, 52° and 60°. A close-up view of the solar collectors in the ground array is provided in Figure 2.1.

The working fluid used is a 50 percent-by-volume mixture of water and ethylene glycol, which is pumped at a variable flow rate based on collector fluid temperature differential. The thermal energy so collected is transferred via heat exchangers to 2500 gallons of water contained in a buried, precasted reinforced concrete thermal storage tank. The existing heating system was a natural gas-fired, forced hot-air heating system. The solar energy system supplements this system by using a heat exchanger installed in the furnace supply plenum. The meteorological monitoring system includes a spectral pyranometer mounted atop the roof array for measuring solar insolation, and two Air Force tactical weather towers, one for measuring wind speed and wind direction, and the other for measuring dry-bulb temperature and dew point.

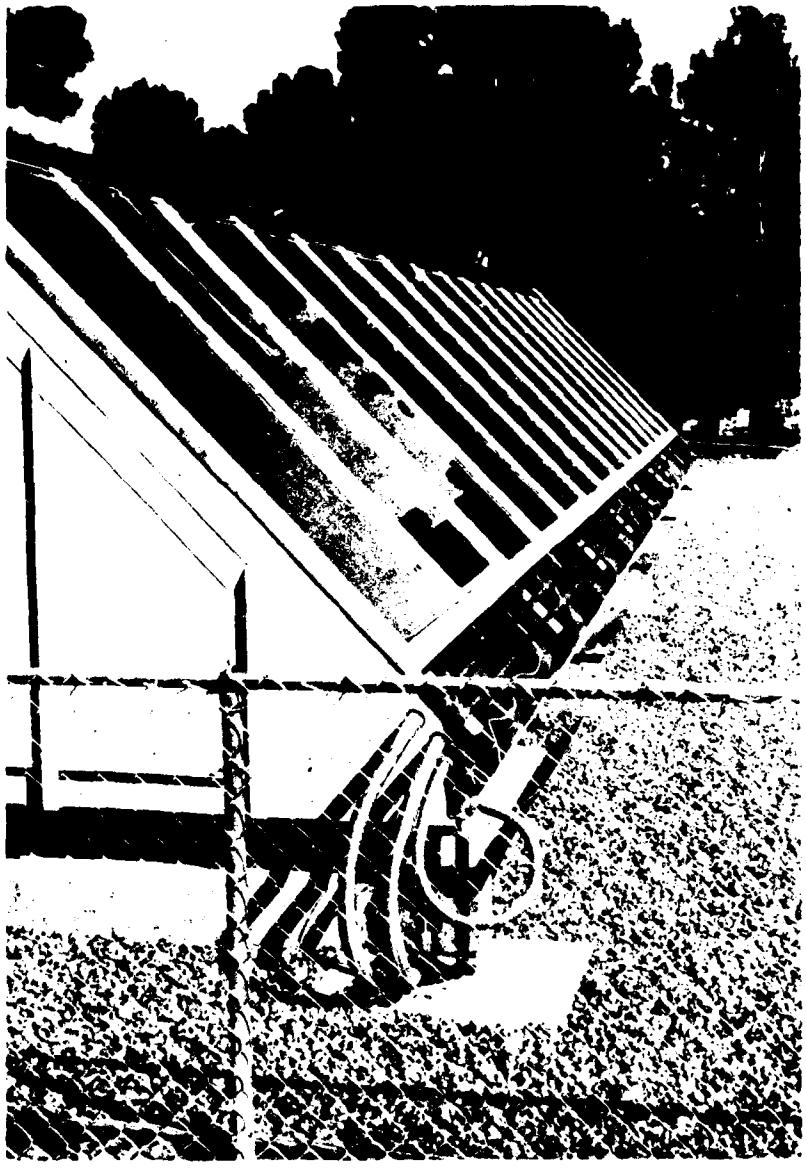


Figure 2.1 Solar Collectors on the Ground Array
(NOTE: Flashing is removed to expose supply and return line header pipes.)

Two identical houses are involved. One house, designated the Solar Test House, received the actual modification and the other house, designated the Control House, was selected to serve as the performance benchmark for test and evaluation purposes. The Control House is operated in a conventional manner and natural gas and electricity consumption are monitored as well as interior temperatures. Both houses have the same solar orientation. The houses are three bedroom, two-bath Capehart, single family units with basements and carports. They have approximately 1200 square feet of living space upstairs and 700 square feet in the basement.

It is the belief of Air Force Academy officials that the most gains to be made in solar energy technology lie in control theory rather than in solar collector technology itself. One of the most prominent features of this project has been its instrumentation and control system, built around a microcomputer and an extensive sensor and control network. This system not only collects information from the various sensors and records it on readable roll paper (as well as on paper tape so that may later be computer processed), but it also controls the mechanical functions via a readily modified control program.

CHAPTER 3

PROGRAMMING

3.1 Concept Development

In response to the curtailment of interruptible natural gas service to the United States Air Force Academy during the period December 1972 to May 1973, Air Force Academy officials initiated a series of recovery programs which included a significant base-wide energy conservation program, the construction of an additional fuel oil storage tank adjacent to the main central heating plant and a serious investigation of developing an alternate unconventional energy source. These programs were initiated, not only because of the severe economic impact just experienced on the operating budget, but also because of the possibility of future natural gas curtailment. Of the alternate unconventional energy sources considered, solar energy was identified as having the greatest potential for use at the Air Force Academy. The primary reason underscoring this decision was the Air Force Academy's geographic location which permits a significant amount of high quality sunlight.

In late spring 1973, the Air Force Academy Faculty, at the direction of the Superintendent, completed a staff study on the feasibility of adopting solar energy systems for the space heating of buildings. It was recommended that the Air Force Academy not participate in a solar energy construction program at the time due

to the unfavorable economics which prevailed. Rather, the Air Force Academy should monitor the Federally sponsored research being done in solar energy (largely through the National Science Foundation at the time) and perhaps participate in it. As a result, the Superintendent initiated a series of communiques with the Air Force Chief of Staff outlining the experience the Air Force Academy underwent as a result of the natural gas curtailment, and suggested the use of solar energy as a possible solution for the future and in so doing offered the Air Force Academy as a demonstration site.

As a result of this tender and with the assistance of Headquarters Air Force Systems Command, an informal committee was developed which became known as the Air Force Solar Energy Working Group (Civil Engineering and Facilities). Chaired by the Professor and Head of the Department of Civil Engineering, Engineering Mechanics and Materials, at the Air Force Academy, this committee was comprised of engineers from Headquarters Air Force Civil Engineering, various Air Force Systems Command laboratories and the Air Force Academy. This committee met at the Air Force Academy on 27 September 1973. It was the first time that the Air Force had considered using solar energy for the heating and cooling of its real property, the justifications for such considerations being to help offset rising utility costs from conventional fossil fuels and to guarantee mission continuation in the face of a threatening energy crisis. Specifically, consideration was to be given to establishing an experimental research and development capability in solar energy with a demonstration project

at the Air Force Academy. As a result of this meeting, it was decided to prepare a proposal for retrofitting some Air Force Academy military family housing to solar energy and submit it in the National Science Foundation Research Applied for National Needs Program (NSF/RANN).

Shortly before this committee met, President Nixon, in his 29 June 1973 energy message, established "Project Independent" which established a national goal of total energy self-sufficiency by the mid 1980's. The Atomic Energy Commission was tasked to develop a program in cooperation with other Federal agencies to promulgate this goal. A tentative funding level of $10 billion was established for a five-year program to support projects that would either support the goal of achieving the national capability of energy, self-sufficiency or support research that promised to provide new options for meeting future energy needs. Responding to the AEC's national energy R&D program call on 11 September 1973, the Air Force Academy submitted two proposals through Air Force Systems Command channels. One proposal dealt with the investigation of the most promising techniques for using solar energy to directly heat a military family housing unit, and the second dealt with the investigation of the most promising techniques for using wind-generated electric power for a similar housing unit. At Headquarters Air Force, these two proposals were integrated into one project submittal and received a rank order priority of 17 out of 47. Although never funded, this information was used as reference material by such planning groups as the Air

Force Energy Research and Development Steering Group, and the Energy Research and Development Administration, which was established in January 1975 as a result of the Energy Reorganization Act of 1974, and consolidated the alternate energy research activities of the Atomic Energy Commission, the Department of Interior, the Environmental Protection Agency, and the National Science Foundation.

Shortly after the Solar Energy Working Group (Civil Engineering and Facilities) had met at the Air Force Academy, work began in earnest on the proposal to be submitted to the National Science Foundation. The only change made was that rather than the retrofit scope of work envisioned being directed to military family housing units, it was instead redirected towards a large institutional building, Fairchild Hall, the main academic building at the Air Force Academy. The major reason for this change was economics. The military family housing at the Air Force Academy represented only a small percentage of the base energy consumption in the fall of 1973. This fact, more than anything else, led Air Force Academy officials to Fairchild Hall because of its significant energy consumption. In February of 1974, the proposal "Demonstration and Development of Solar Energy for the Heating and Cooling of Institutional Building Facilities" was submitted by the Air Force Academy to the National Science Foundation for consideration in the Research Applied for National Needs Program.

In October 1973, Mr. McCormack of the United States House of Representatives introduced a bill to the Congress calling for the widescale demonstration of practical solar heating technology in

three years and the combined solar heating and cooling technology in five years in the public sector. Known as the Solar Heating and Cooling Demonstration Act of 1974, it was signed into law by President Ford in September 1974. It called for significant participation by the Department of Defense because of their massive real estate holdings and directed its initial attention to residential housing.

Also, in October 1973, the Research Applied for National Needs Public Technology Projects Office contracted with three commercial companies (General Electric, TRW and Westinghouse) to conduct extensive feasibility studies for using solar energy for the heating and cooling of buildings to include analysis of such influencing factors as environmental, sociological, technological and economics. The results known as the Solar Heating and Cooling Buildings (Phase 0) Reports were completed in May 1974. The reports more or less all supported each other and concluded that solar energy has the potential for making a significant positive effect on the nation's energy economy by the end of the present century. They went on to point out that the greater market capture potential in the private sector would be found in the new construction arena and not the retrofit arena.

The year 1974 saw considerable solar energy related activity nationally. At the Air Force Academy, significant activity in solar energy was also pursued, and continued in-house work relative to the scope of work in the proposal submittal to the National Science

Foundation was pursued. In addition, blocks of instruction on solar energy were presented to cadets in engineering courses and cadets began fabricating solar collectors for testing.

In November 1974, the Air Force Energy Research and Development Steering Group released its final report. This group was formed in January 1974 at the direction of the Air Force Chief of Staff under the Chief Scientist. It has the responsibility of reviewing the impact of energy shortages on the future of the Air Force and to recommend future research and development efforts in response. With regard to installations-oriented energy consumption, the R&D responsibilities were the responsibilities of all services and remote installations were to be made energy self-sufficient. Because of DOD policy established by the Office of Installation and Logistics, the Air Force was to rely on the private sector and non-DOD agencies to develop new energy sources such as solar energy for ground based installations. On the basis of these findings, together with the DOD associated goals of the Solar Heating and Cooling Demonstration Act of 1974, and the National Science Foundation sponsored "Phase 0" reports downplaying the importance of solar energy retrofit schemes in the private sector, it became clear that the Air Force needed a retrofitted solar test house laboratory that would be capable of readily accepting commercially-manufactured solar energy hardware for evaluation for military use and the development of definitive designs. Accordingly, Air Force Academy officials withdrew the proposal that had been submitted to the National Science Foundation in February of

1974 and began preparing a proposal for military family housing solar energy retrofit that would be internal to the Air Force. The proposal was to focus on retrofit because of the peculiar needs of the Air Force; i.e., with approximately 150,000 family housing units in its inventory and a stabilized real property base, the Air Force predicted only a marginal requirement for the need for new construction.

3.2 Project Establishment and Funding

In December 1974, at the direction of Air Force Academy officials, work began on preparing a proposal for the solar heating retrofit of military family housing. This work was a joint effort between the Department of Civil Engineering, Engineering Mechanics and Materials of the Faculty and the Office of the Deputy Chief of Staff for Civil Engineering. Approved by Air Force Academy officials in early March, the official project proposal, entitled, "A Proposal for Solar Heating of Family Housing at the United States Air Force Academy," was briefed to the Commander and Staff of the Air Force Systems Command by the Superintendent of the Air Force Academy. On the basis of the briefing, the proposal was approved and immediate funding authorized. Within the Air Force Systems Command, the Air Force Aero Propulsion Laboratory was identified as the initial support laboratory.

As a result of the Air Force Systems Command approval of the proposal, project documents were prepared and sent forward to Headquarters Air Force Civil Engineering on 19 March 1975, requesting

approval. This approval was obtained on 2 April 1975.

In early spring of 1975, it was decided that all Air Force Systems Command fiscally-sponsored research done at the Air Force Academy would be processed through and administered by the Frank J. Seiler Research Laboratory (FJSRL). This new program was scheduled to go into effect on 1 July 1975. During the interim period, it was decided that this proposal would be administered in this manner as a "test case" in order to develop the necessary implementation protocol for this program.

The Frank J. Seiler Research Laboratory received Project Order FDOP0075P4019 for $45,000 on 21 April 1975 from the Air Force Aero Propulsion Laboratory on behalf of the Air Force Academy to accomplish the work outlined in the proposal. The Frank J. Seiler Research Laboratory established Job Order JON 7903-03-75 to support the work effort and, in turn, the Base Civil Engineer established Work Order 81016 (BCE Support for Conversion of Testing Two Housing Units for Solar Heating) for the same purpose. Due to the late start on this project order, which expired on 30 June 1975, it was necessary to initiate on 13 May 1975 a request for forward financing authority in the amount of $35,000 for three months in order to cover the anticipated contract construction period. In addition, a general extension for one month to allow sufficient time to obligate the funds for obtaining the Goverment-furnished material in support of the contract construction work and the Government-installed equipment in support of the instrumentation and control system was requested.

This request was subsequently granted by the Air Force Aero Propulsion Laboratory on 2 June 1975.

On 26 June 1975, the Air Force Aero Propulsion Laboratory sent Project Order FDOP0076P4002 for $11,000 to the Frank J. Seiler Research Laboratory for continued support of the solar heating retrofit project. This project order was subsequently accepted on 15 July 1975. On 22 August 1975, this project order was amended with a $3,500 increase, thus providing a total funding authority of $15,000. The amendment was accepted on 8 September 1975.

Earlier in July 1975, Headquarters Air Force Civil Engineering established the AF/PRE Solar Energy Task Force which was charged with the responsibility of developing criteria, establishing policy, reviewing and recommending action for all Air Force solar energy projects involving real property. In early November 1975, this group tasked the Air Force Civil Engineering Center with research and development responsibilities in this area.

Accordingly, in December 1975 with both the acquisition and systems check-out phases completed, the test and evaluation phase was begun. Entitled, "A Proposal for the Test and Evaluation Phase of the Project Solar Heating Retrofit of Military Family Housing," this proposal was submitted to the Air Force Civil Engineering Center on 7 January 1976. This proposal was accepted by the Air Force Civil Engineering Center and subsequently two project orders for a total of $10,000 were issued on 25 February 1976 (PO 76-027, $3,000 and PO 76-028, $7,000). These project orders were accepted in behalf

of the United States Air Force Academy by the Frank J. Seiler Research Laboratory on 22 March 1976.

3.3 Project Execution

Because of the diverse technical nature of this project, its accomplishment has been promulgated by three different Air Force Academy engineering organizations - the Department of Civil Engineering, Engineering Mechanics and Materials, and the Department of Electrical Engineering of the Faculty, and the Base Civil Engineers. The direction of the Air Force Academy Solar Energy Program is shared on a co-director basis between the Professor and Head of the Department of Civil Engineering, Engineering Mechanics and Materials, and the Deputy Chief of Staff for Civil Engineering.

The day-to-day program management and administration is accomplished by the Air Force Academy Solar Energy Investigation Team which is composed of personnel from the three engineering organizations previously mentioned. The Solar Energy Investigation Team is directed by the program principal investigator. This team was informally established in December 1974 and has seen the family housing retrofit project through all of its phases of accomplishment. These phases include the final programming, design, logistics planning, construction contracting, in-house instrumentation and control system installation, system start-up, and data acquisition with its follow-on data processing leading to the beginning of the test and evaluation phase.

CHAPTER 4

CONTRACTING

4.1 Scope of Work

As the design phase neared completion, consideration was given to field construction. The required work fell into two general categories. The first category involved structural, mechanical and electrical work associated with the installation of the solar energy system and was considered to be in the realm of general shop work. The second category involved the instrumentation and control system and allied microcomputer support systems. This category of work was considered outside the realm of the capabilities of general shops.

4.2 Method of Accomplishment

In considering the first category of work, two choices were available for the method of accomplishment. The first choice was to use in-house forces from the Base Civil Engineer shops. Because of limitations against the amount of minor construction these forces are allowed to accomplish annually, coupled with the short scheduling lead time allowed and the heavily committed maintenance and repair workload of these forces, in-house forces could not be utilized. Thus, the second choice of entering into a contractual agreement via formal advertisement and negotiation with a general contractor was employed. In this regard, the following considerations were weighed for determining the contracting method:

a. a solar heating retrofit involves the construction of systems and utilization of equipment generally foreign to general and sub-contractors;

b. the experimental research and highly visible nature of this project required a high level of workmanship;

c. a few contractors in the Denver, Fort Collins and Colorado Springs areas were familiar with solar heating construction projects;

d. definite fund limitations existed;

e. contractors generally appeared leary of the emerging solar energy technology and did not appear anxious to bid on such a project.

Based on these considerations, the decision was made to negotiate a contract with contractors in the area familiar with solar energy projects. Accordingly, a Request for Proposals (RFP) was issued to selected contractors rather than having issued a general Invitation for Bids (IFB) against which all qualified contractors could bid.

It was determined that it would be directly beneficial to the Air Force to accomplish much of the project logistics in behalf of the contractor by providing the solar energy related hardware in the form of Government-furnished equipment and material. This decision was based on the following observations:

a. being unfamiliar with these items, the contractors might inflate their proposal quotes;

b. extended delivery times required by these items would delay the initiation of construction;

c. items purchased by the Government could be tested and/or modified prior to issue to the contractor;

d. direct communications between the manufacturer and the Government representative could result in faster deliveries of correct items.

Accordingly, the solar collectors, the various heat exchangers, various electrical signal cables, flow control valves, flow measuring units, the ethylene glycol and some electrical switches were identified as Government-furnished equipment and materials. The installation of the instrumentation and control system and allied microcomputer support systems were installed by engineers of the Air Force Academy Solar Energy Investigation Team. Base Civil Engineer in-house shop forces completed the installation of the preheat domestic hot water system along with minor basement modifications and mechanical adjustments during the initial start-up period.

4.3 Contract Negotiations

All contractors solicited responded to the Request for Proposal issued, but only two submitted acceptable proposals. Of the two unacceptable proposals, one contractor proposed a "cost plus only" statement and the other failed to provide a certified performance bond. After a period of intensive study and discussion, a construction contract was awarded to Dan Howells and Sons Construction Company

of Colorado Springs on 15 July 1975 in the amount of $30,533.39.

4.4 Cost Summary

The costs incurred during the acquisition phase of this project are included in Appendix H. The high costs involved are indicative of the research and developmental nature of the project and are not related to the costs that would be experienced in a field-scale retrofit prototype application. Inasmuch as a field-scale laboratory facility involving two different housing units was constructed in this project, significant high quality structural and mechanical redundancy was required during the minor construction phase that involved many unknowns.

4.5 Government/Contractor Relations

In order to add continuity to the construction phase of this project and to emphasize good communications between the Government and the contractor, members of the Air Force Academy Solar Energy Investigation Team maintained communication with the contractor. This action resulted in the development of an excellent working relationship between the Government and contractor. It became apparent early in the construction phase that the general contractor and his sub-contractors were being motivated by a desire to learn the methods of applying an exciting new technology. Their pride in workmanship and eagerness to contribute many beneficial suggestions during the contract construction phase of the project resulted in a fine quality, more functional and attractive product required by a highly visible

research project of this nature. The detail and completeness of the original design when supported by this cooperative relationship in the field resulted in the construction phase being completed without a single change order.

4.6 Summary

In retrospect, on the basis of the experience gained during the contract construction phase, it is recommended that future contract work be done via an Invitation for Bids rather than with a Request for Proposal and the follow-on negotiations. The Request for Proposal method served this project well in view of the experience base that existed in the summer of 1975 and in view of the research and development nature of the USAFA Solar Test House.

However, in the past year, there has been significant activity in solar energy by the construction industry and many lessons have been learned. As a result, it may be difficult to justify, within procurement channels, further Request for Proposal contracting methods for solar energy construction.

In summary, it is recommended that future solar energy construction projects be formally advertised and not negotiated. Although a small degree of added experience can probably be gained, it will be most likely obtained at an added cost. The eagerness of contractors to gain experience in this new field will probably outweigh their inexperience and can directly impact on the future Government solar energy programs.

CHAPTER 5

SOLAR TEST HOUSE FACILITIES ACQUISITION

5.1 Quarters Description and Selection

The Air Force Academy family housing consists of 1263 units. Indigenous and senior housing account for 63 of these units, and the remaining 1200 units are Capehart units which were constructed in 1958 and 1959. These Capehart units are a combination of duplexes and single-family dwellings with 14 basic floor plans that are situated in two different locations - Pine Valley and Douglass Valley.

Construction consists of structural wood frames with brick veneers and masonite highlight siding panels. The roofs of the quarters originally had essentially flat pitches of four-ply built-up roofing construction. Currently, these roofs are being modified to pitched roofs with pressboard sheathing and shingle surface in order to make them more wind resistant. These quarters have carports, basements, hardwood floors and fireplaces. Usable floor space runs from 875 to 1412 square feet. These units are typical of Air Force family housing in the CONUS today.

In selecting the type of quarters for this project, many factors were considered. Early in the program, the decision was made to use two houses in this project. One house was to receive the actual solar energy system modifications and be designated the USAFA Solar Test House. The other house was to be identical as possible, receive no modifications other than instrumentation, and be operated in a

conventional manner. It was to be designated the Control House and serve as a thermodynamic performance reference for the USAFA Solar Test House. This decision was made as it was felt that there would be more credibility if the Solar Test House was compared with an actual house rather than a computer-simulated one.

Thus, selection criteria dictated that the environment surrounding, as well as within, both units be as identical as possible. The factors affecting these requirements were:

a. sun orientation and loading;

b. wind orientation and loading;

c. family size and age group of the occupants.

Duplex styles were ruled out as a result of these considerations. Of the remaining four styles available, only one (the Type 12 Unit) existed in sufficient numbers (196 units) in both housing areas to be considered typical enough for consideration. In addition, the Type 12 Units included a totally unfinished basement which could provide the area required for the mechanical room.

The selection of the exact two Type 12 Quarters to be utilized involved determining which quarters would be vacant during the construction period and grouping those with a similar exterior environment. This procedure resulted in selection of three possible combinations. The final selection identified the USAFA Solar Test House (Quarters 4518I) and the Control House (Quarters 4511J) in Douglass Valley. This location has a latitude of N 38° 58', a longitude of W 104° 51', and an approximate elevation of 6903 feet. These two units have identical floor plans and orientation. They are located on the same side of the street, in the

same relative position in their respective housing clusters, and are within 1000 feet of each other. They are identical in every respect except the location of their back doors and the pitch of their roofs.

The Type 12 Quarters selected have three bedrooms, two bathrooms, a living room, a dining room, a kitchen and a carport. A typical floor plan is shown in Figure 5.1. The finished living area upstairs contains 1194 square feet and the unfinished basement area contains 708 square feet. Elevation views of the house with the roof array are shown in Figure 5.2.

Neither of the units were altered with respect to the location or extent of energy conservative features or materials. Both units include storm doors and windows and utilize the natural gas-fired, forced air heating.

To insure the proper environment and controlled heating system of both houses, engineering officers and their families, familiar with the project, were chosen to occupy them.

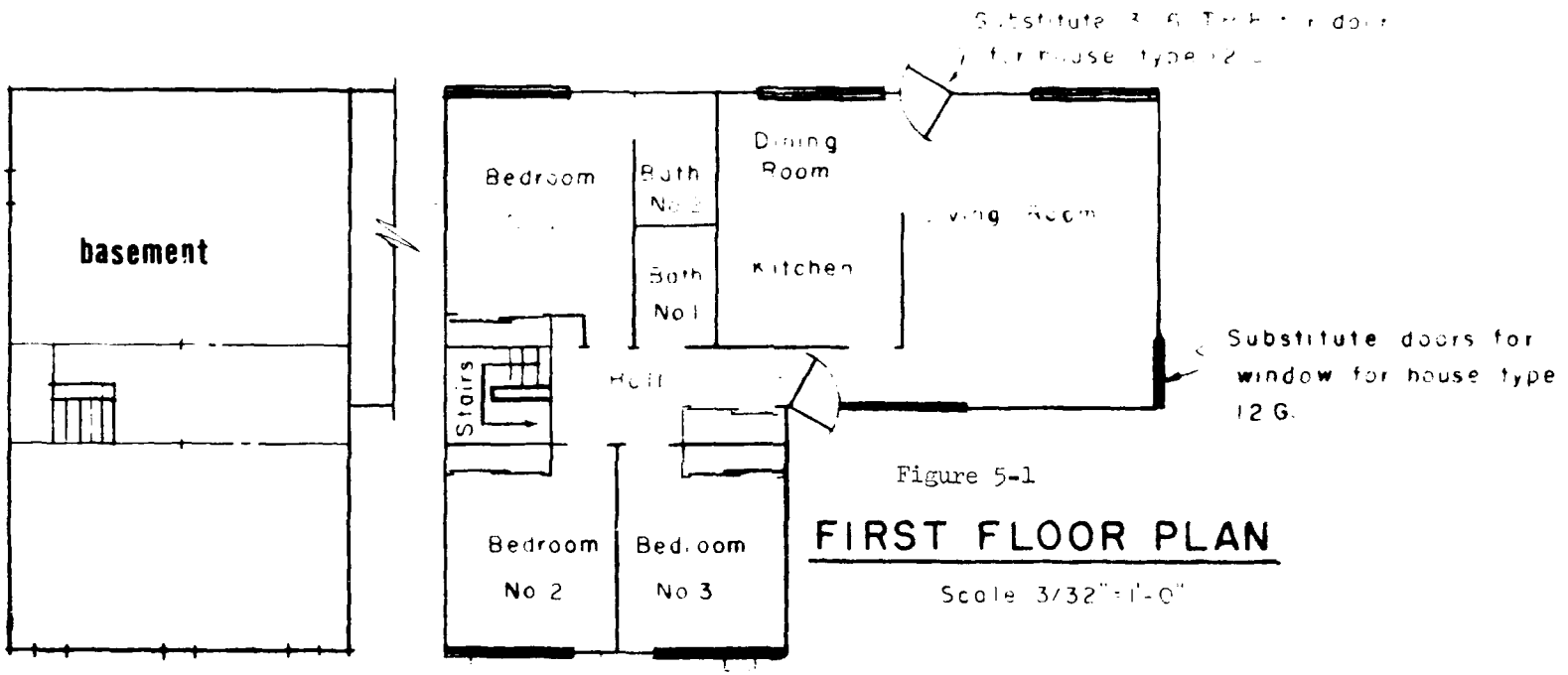


Figure 5-1

FIRST FLOOR PLAN

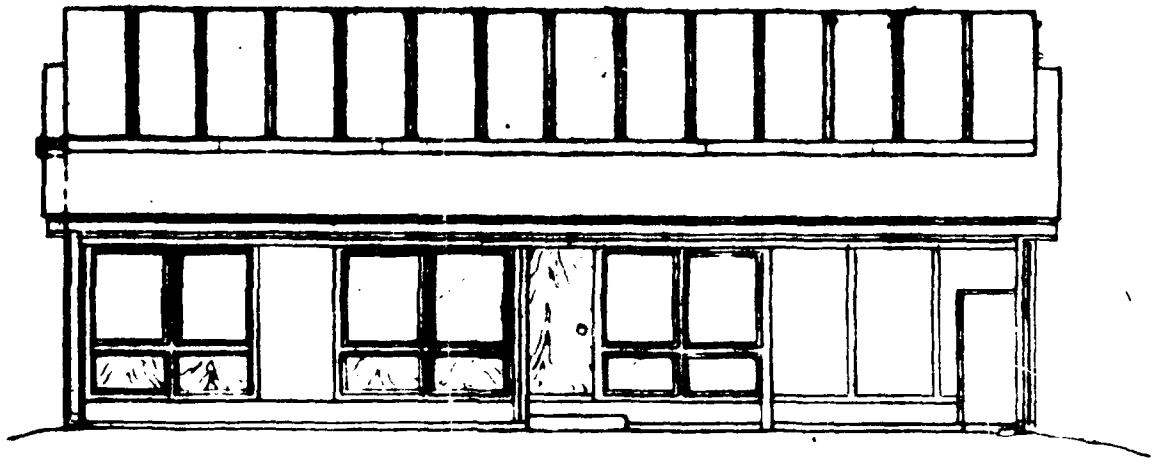
Scale 3/32"=1'-0"

Notes
Ceiling heights = 8'-0
1 fireplace
House types 12, 12G, & 12N similar except as noted
See plan

BUILDING TYPE 12, 12G & 12N

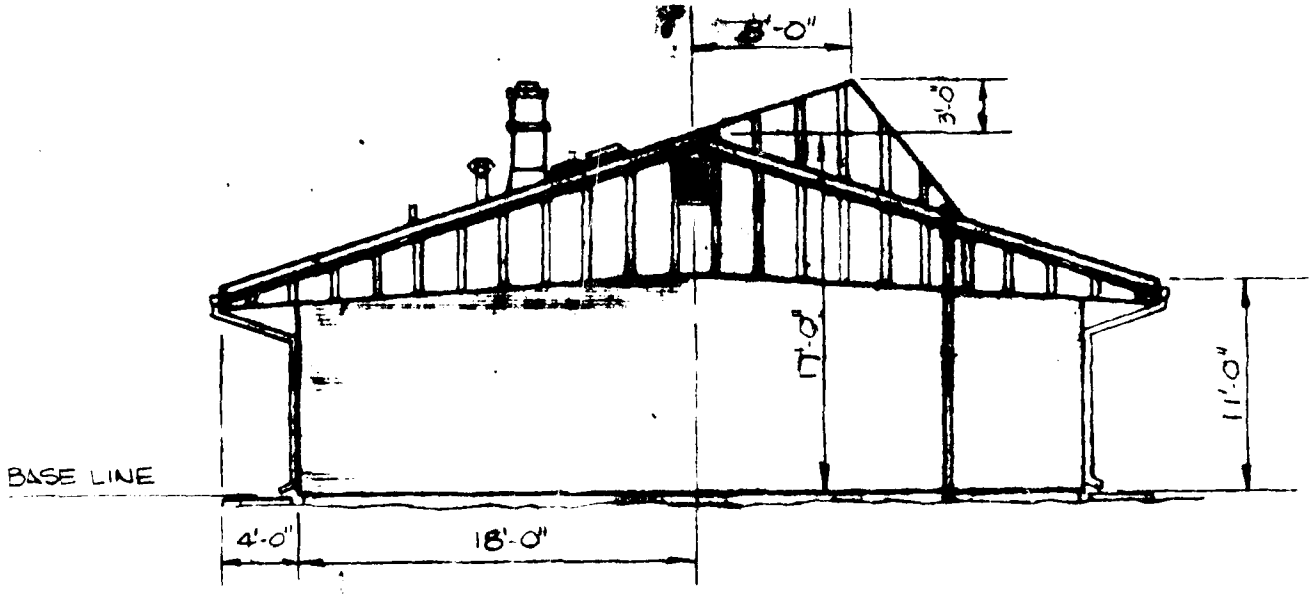
196 BUILDINGS
196 LIVING UNITS

Figure 5.2 Elevation Views



SOUTH ELEVATION

SCALE: 1/8" - 1'-0"



WEST ELEVATION

SCALE: 1/8" = 1' 0"

5.2 Heating Demand

The original heating system for the quarters was the natural gas-fired, forced hot-air heating system. Natural ventilation was provided in all living areas with the exception of the kitchens and bathrooms which utilized mechanical exhaust systems.

Weather conditions at the Air Force Academy, on the basis of degree days (heating/reference 65°F), may be classified as moderate to severe. Degree-day data for the 13 years are reported in Appendix A. Degree days are experienced all year around, although the normal heating season begins in September and ends in May. The Air Force Academy receives approximately 7425 degree days annually.

At the time of the design, the critical winter conditions governing design were -6°F for the outdoor temperature and 72°F for the indoor temperature for all the rooms except the bathrooms which were designed for 75°F. The basements were designed for 65°F and crawl spaces, 45°F. Under these conditions, the original design heating load was 70,430 Btu/Hr. Accordingly, the original furnace was designed for a maximum rated capacity of 83,000 Btu/Hr at an air-flow rate of 1333 cfm.

Recently, another heat loss analysis has been accomplished on the Type 12 Quarters in accordance with more up-to-date provisions. Based on an outside design temperature of -2°F and an inside temperature of 70°F, the design heating load is approximately 51,000 Btu/Hr. This analysis is in Appendix B.

On the basis of natural gas consumption monitoring done at the Air Force Academy since 1970, it is estimated that the average annual heating demand is approximately 30,000 Btu/Hr.

5.3 Ground and Roof Array

One of the unique and key features of this applied research and development project is the utilization of a split solar collector array system. In all probability, in the actual construction, either a roof array or a ground array would be used, rather than a combination. Because of the laboratory nature of the USAFA Solar Test House, it was decided to use both types of arrays for the benefit of experience.

Roof-mounted and ground-mounted solar collector arrays have inherent advantages and disadvantages. A roof array:

a. can be utilized in a high density building area, where shadowing is a problem from other structures;

b. requires an existing roof which can carry or be strengthened to carry the increased loading (typically 10 to 15 pounds per square foot more). In addition, the roof must have a proper sun azimuth (south in the northern hemisphere) and must be peaked or be capable of being peaked to develop the required sun angle (function of latitude and intended use);

c. does not usually present a terrestrial glare problem;

d. is not as susceptible to breakage due to accident or vandalism;

e. is more costly to construct and maintain due to accessibility;

f. has a strong impact on the aesthetics of the structure.

On the other hand, a ground array:

a. can be utilized in areas where unobstructed land is available (no shadowing);

b. can be sized to serve more than one housing unit;

c. due to accessibility, it can be readily constructed and is thus less costly;

d. can create terrestrial glare problems;

e. does not require extensive structural modifications to the housing unit;

f. can be entirely prefabricated.

By using a split solar collector array system, with both containing an equal number of identical solar collectors, the opportunity was provided to directly compare the operating efficiencies, maintenance, susceptibility to vandalism and response to snow and wind load.

One unique feature of the ground array is its ability to be rotated with respect to the seasonal altitude of the sun. This feature was not incorporated in the roof array due to structural limitations imposed by the existing roofing system. This feature is provided for by a "hinge" and "saddle system." The front (south facing) portion of the ground array is supported on hinges which bear on the footings. The rear of the array is supported on saddles which are, in turn, bolted to the footings. Three sets of saddles currently exist which can be utilized to orient the collector surfaces at either 45°, 52° (same as the roof array) or 60° from the horizontal. Figure 5.3 shows the details of the ground array construction and the hinge and saddle detail. Figure 5.4 shows the saddle details and Figure 5.5 shows the footing detail. Figures 5.6 and 5.7 contain photographs of a saddle and footing after construction.

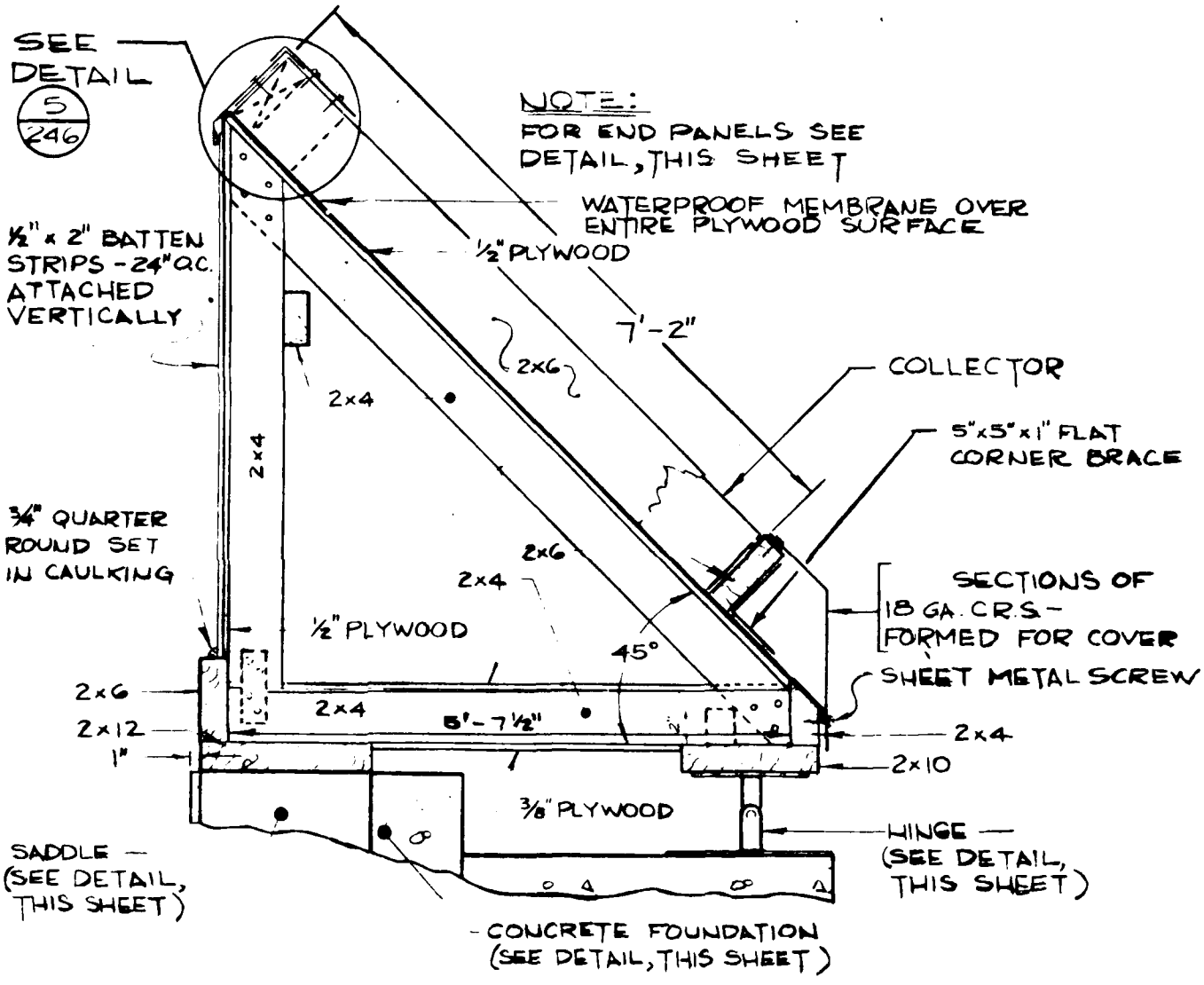


Figure 5.3

GROUND ARRAY FRAME — END VIEW
(OPPOSITE HAND SIMILAR)

SCALE: NONE

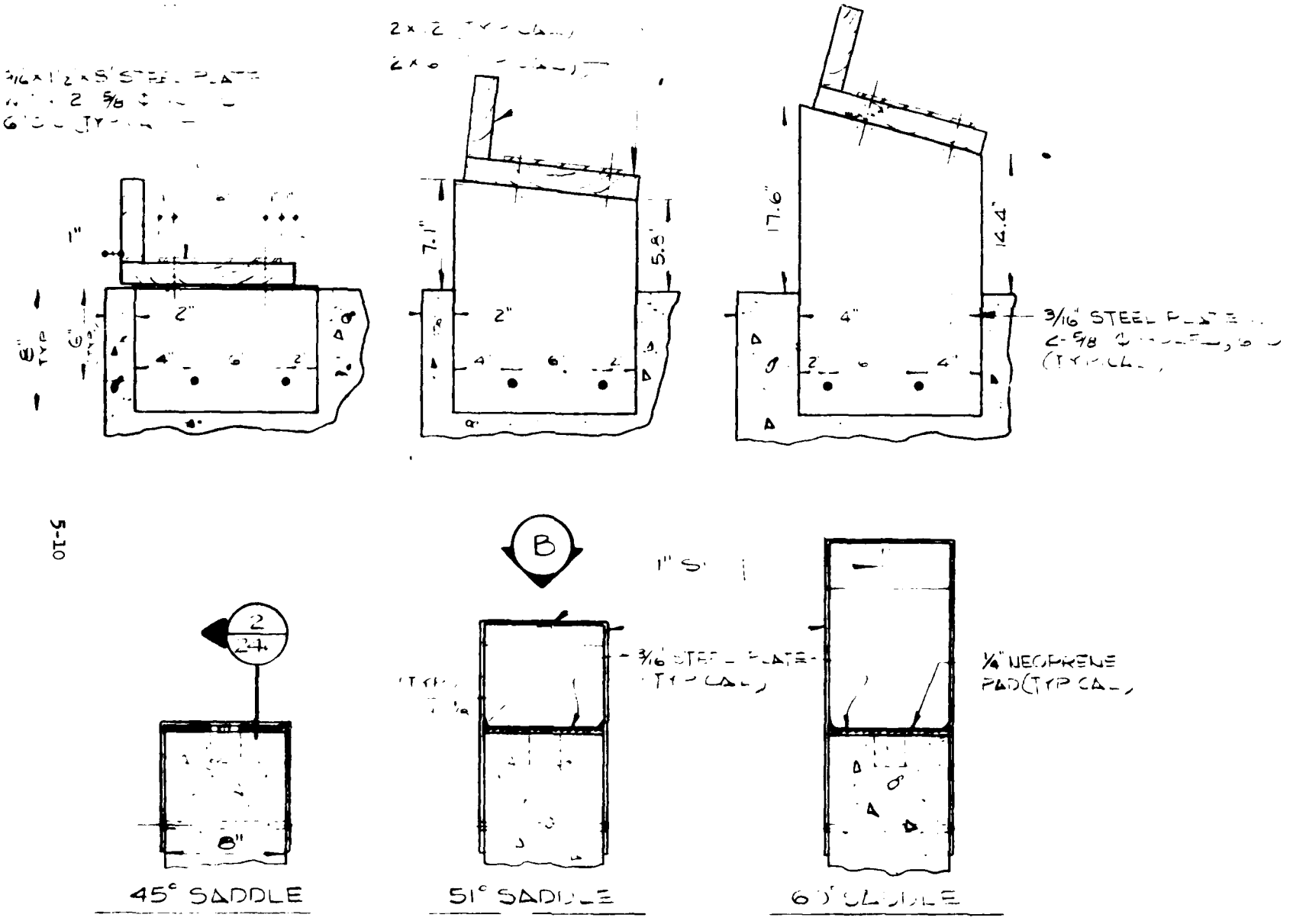


Figure 5.10 SADDLE DETAILS

SCALE: NONE

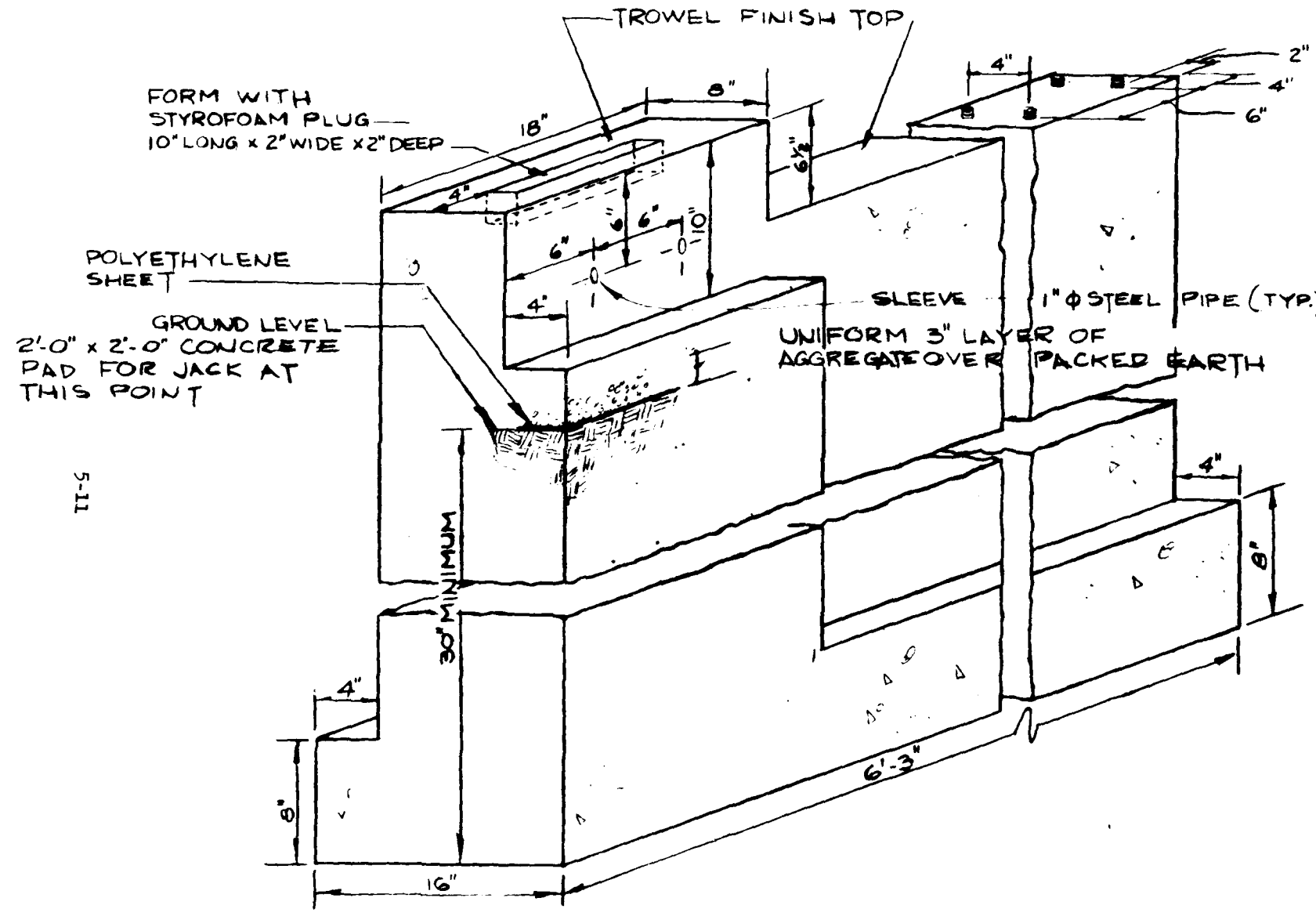


Figure 5.5 FOOTING DETAIL

SCALE: NONE

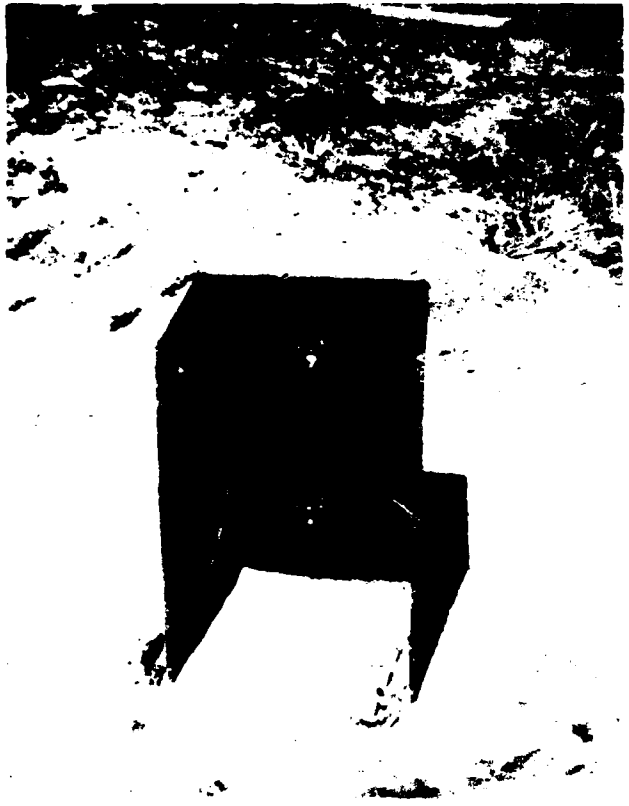


Figure 5.6 Ground Array Footing Saddle

Figure 5.7 Ground Array Footing

The ability to change the angle of a solar collector can be of significant value in regions where solar energy is being considered for both space heating and air conditioning. Even though air conditioning was not a requirement of this project, the experience with and data from this array justified the low additional cost required. Perhaps in time, this ground array with its operating flexibility would have application in the Air Force Bare Base Program.

Another feature of the ground array is that it may be prefabricated. Its overall dimensions are such that it can be constructed on a year around basis utilizing lower cost labor and transported to the construction site in a finished state. Figure 5.8 shows the ground array under construction in the field.

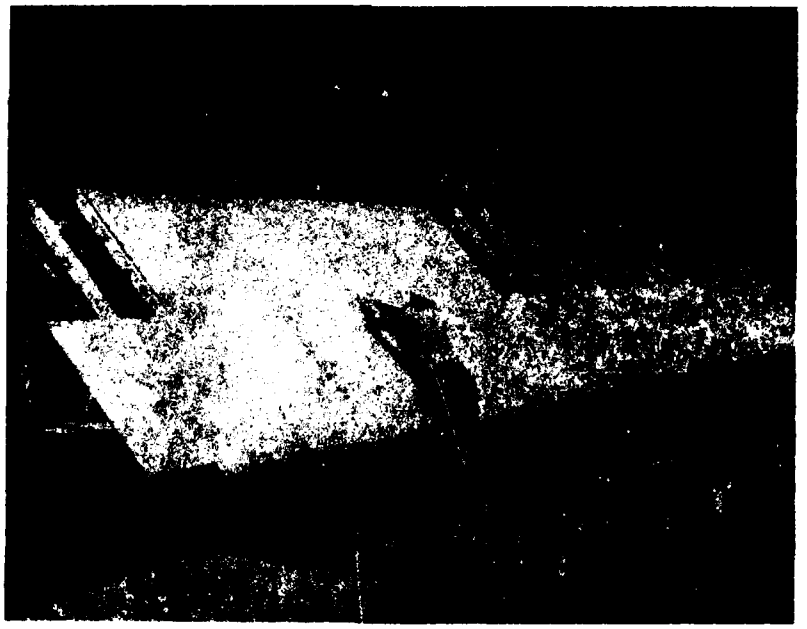


Figure 5.8 Ground Array Under Construction

The modular solar collectors selected for the initial installation rest on a shelf which has been constructed on the array and which separates the solar collectors from the raceway which houses the supply and return line headers for the working fluid. A double layer of asphalt impregnated roofers felt serves as the waterproofing boundary under the solar collectors. Figure 5.9 shows the ground array ready to accept the solar collectors. A light gauge corrosion

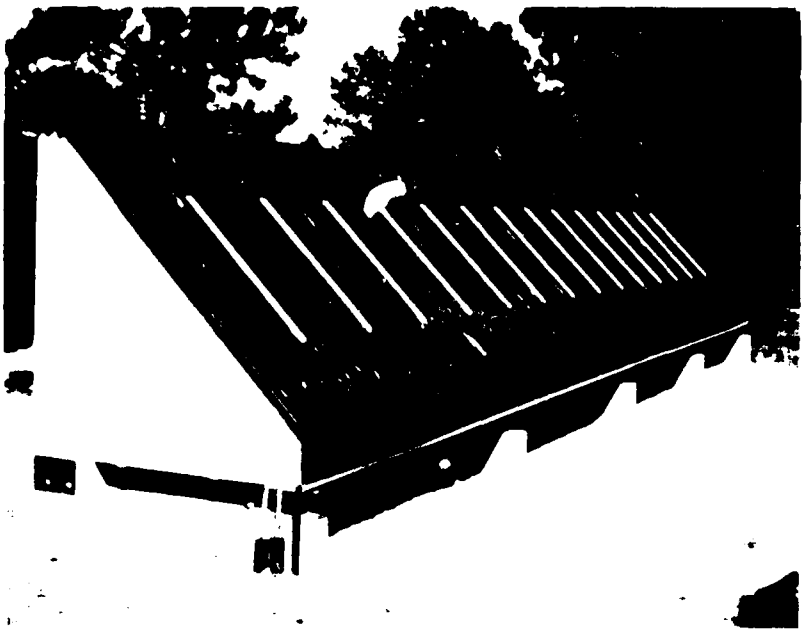


Figure 5.9 Ground Array Ready for the Collectors

resistant steel flashing system then provides the final outer layer of waterproofing and also secures the solar collectors to the array.

Figure 5.10 shows the ground array completed, with solar collectors mounted and flashing installed.

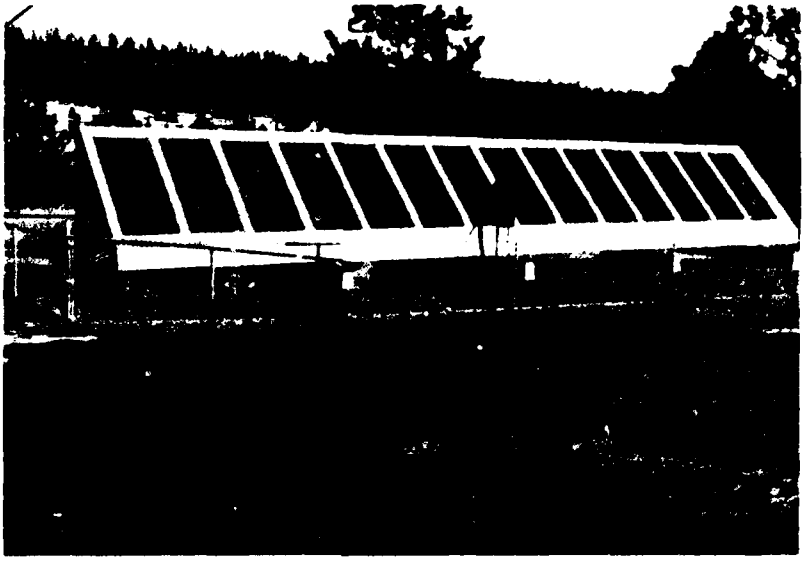


Figure 5.10 Ground Array Completed

The placement of the ground array is governed by correct orientation with respect to the sun and the requirement of a shadow-free area. The ground array was sited 51 feet behind the quarters with its major axis parallel to that of the quarters. Thus, the solar collectors were oriented due south.

In order to prevent shadowing of the ground array during low winter sun periods, the shadows cast by the major objects (test and adjoining quarters) toward the location of the ground array were determined. This involved drafting a plan view of the area, calculating and plotting the shadows of "high points" with respect to time and the

related solar altitudes and azimuths for the worst solar day. Figure 5.11 shows the effects of shadowing during the critical time in late December.

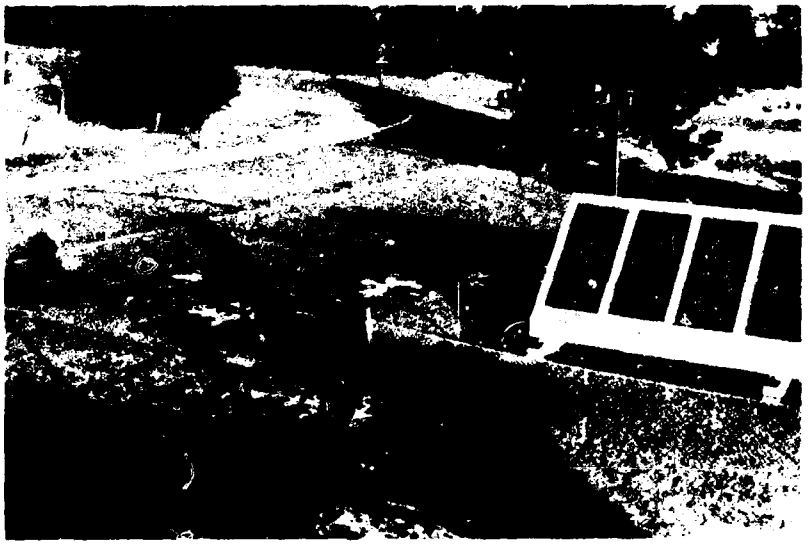


Figure 5.11 Ground Array Shadowing

The roof on the USAFA Solar Test House consisted of the original nearly flat-pitched, four-ply, built-up type construction roof and the modified pitched roof of plywood sheathing and shingle surface. The construction of the roof array consisted of stripping the sheathing and shingles from the upper portion of the south face of the roof in segments and attaching a "parasite" truss which rested on the panel points of the existing truss. This provided a platform approximately 52° from the horizontal for installation of the solar collectors. The 52° angle was arrived at from the algorithm for basic winter heating of the latitude plus 12°. Round

off, plus the location of the panel points, made this 52°. Figure 5.12a shows the construction details of this "parasite" truss. Figure 5.12b and 5.12c show the roof array under construction.

Figure 5.13 Roof Array Completed

The existing truss was initially designed to carry a live (snow) load of 30 psf. Since local conditions have resulted in current design requirements of 20 psf live (snow) load, a computer analysis resulted in the basic truss requiring the reinforcement of only one web member. The parasite trusses were then covered with plywood and waterproofed with a double layer of asphalt impregnated

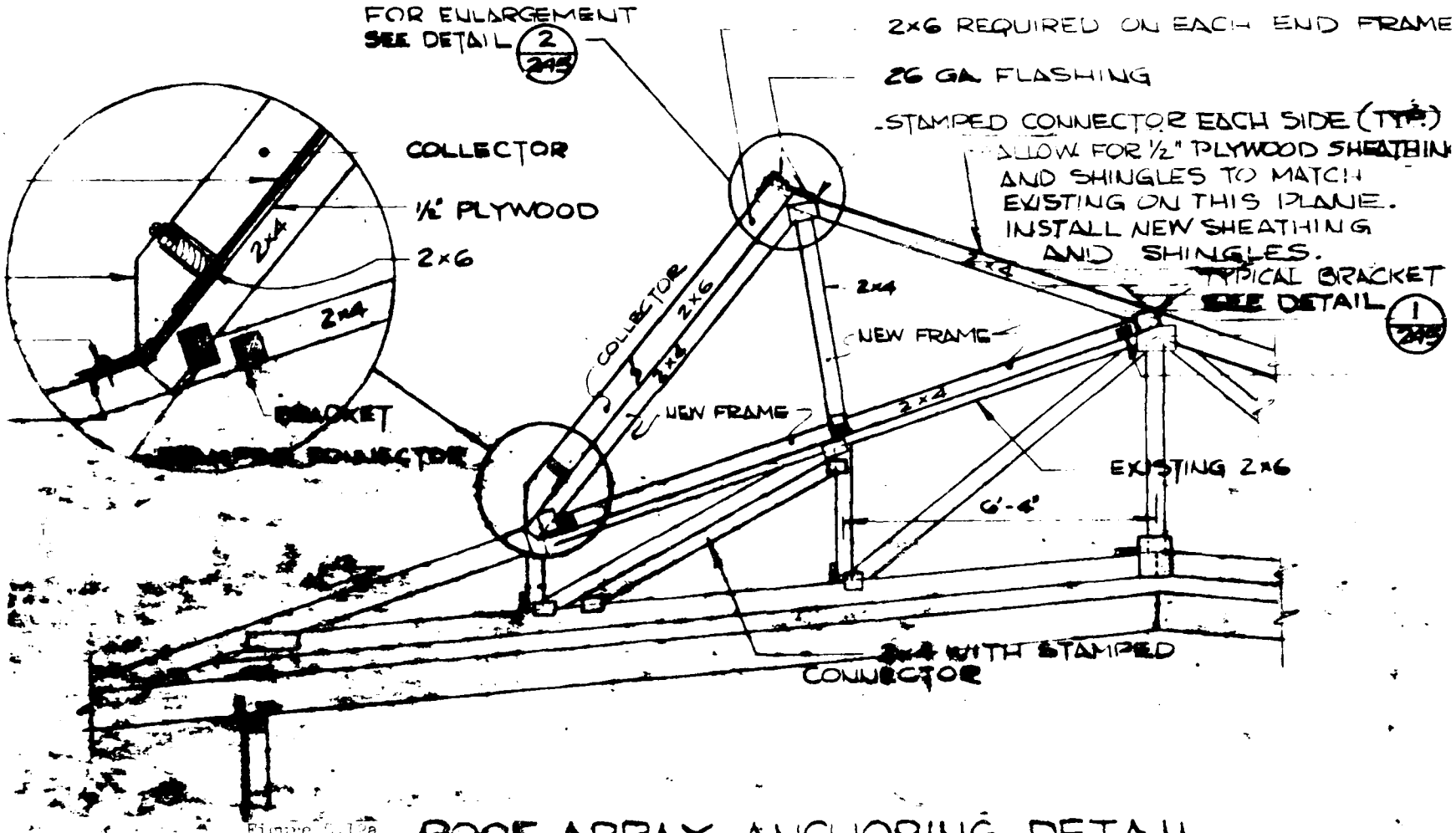


Figure 5.12a

ROOF ARRAY ANCHORING DETAIL

SCALE: NONE

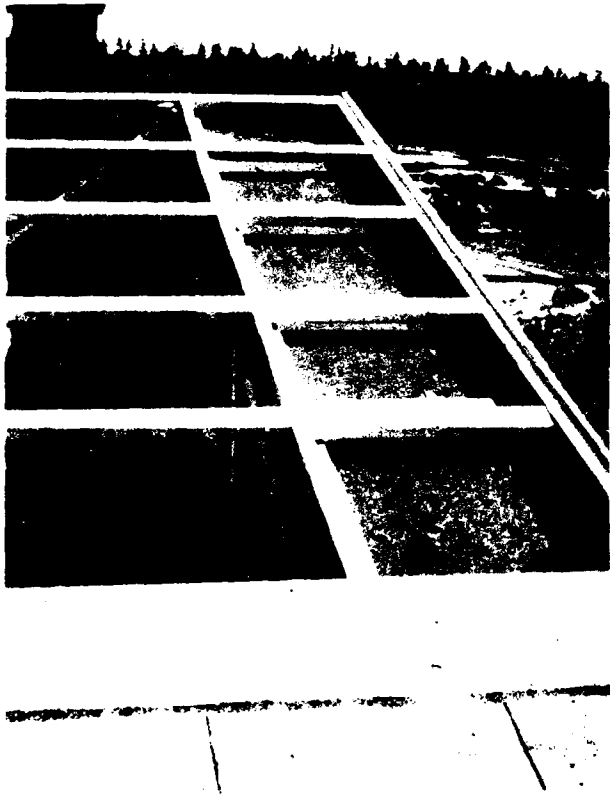


Figure 5.12b Roof Prepared for Parasite Truss

Figure 5.12c Parasite Truss Installed

roofer's felt. Once the collectors had been placed on a shelf similar to that of the ground array and the plumbing completed, a light gauge corrosion resistant steel flashing system provided the final outer layer of waterproofing and also secured the collectors to the array. The dead weight associated with the new array approached 13 psf (pounds per square foot). Figure 5.13 shows the roof array completed with the solar collectors mounted on the flashing installed.

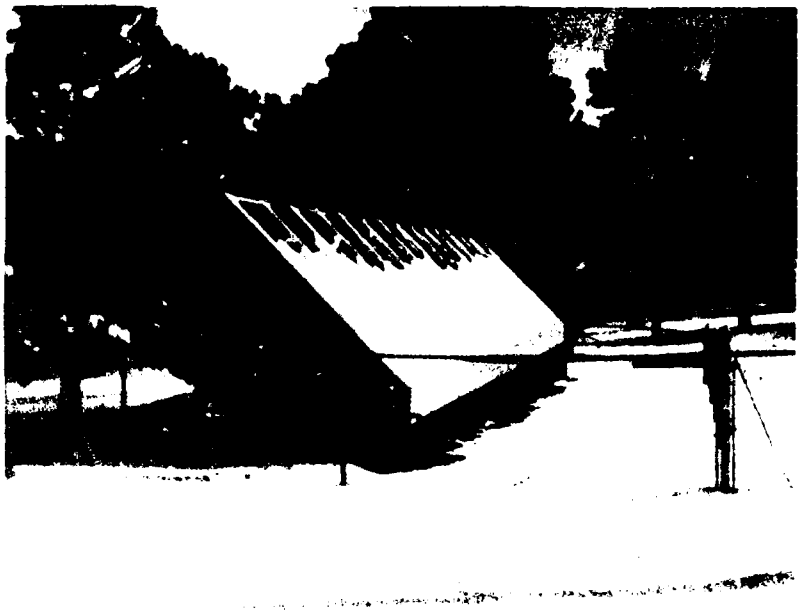


Figure 5.14 Ground Array Snow Loading

Waterproofing initially specified was a neoprene-hypolon type which would soften and run at temperatures in excess of 275°F.

During no-flow conditions, these temperatures could easily be reached by the collectors with obvious unacceptable results. The final waterproofing scheme included a ten mil plastic sheeting over the roofer's felt. During construction, the covered, inoperative solar collectors still heated up sufficiently to melt the plastic sheeting. All sheeting was immediately removed. In turn, the solar collectors were covered with heavy cardboard. Solar collectors must be protected from the sunlight when they are not operating. It was observed that during the construction phase the surfaces of uncovered solar collectors exposed to the sun became so hot that some outgassing occurred that had a derogatory effect on the collectors.

Precipitation in the form of snow and ice proved to be a problem. Figure 5.14 shows the ground array covered with snow. When covered with snow, the solar collectors will not function. Light will penetrate several inches of snow and warm the collector surface sufficiently to melt the snow film adjacent to the outer glazing which, in the case of the ground array, allows the snow to slide off to the ground clearing the collectors. However, the roof stops the sliding snow cover; the snow is removed only by melting because of the mild slope of the roof. This result is an excessive snow load on the roof. This sequence is illustrated in Figure 5.15 a,b,c. After a severe storm, the ground array will clear within the first sunny hour, but the roof array will remain snowbound for two to three days. This problem can be alleviated by designing arrays on the leading edge of structures where the snow may slide and fall clear of the collectors and the supporting roof.

Figure 5.15 Roof Array Snow Loading Sequence

Icing was another problem. It would often be present early in the morning and because of its crystalline structure, it would not dissipate as readily. Manually overriding the instrumentation and control system and pumping heat from the storage tank would quicken its dispersal. Figure 5.16 shows the nature of ice build up on the surface of a series of solar collectors on the roof array.

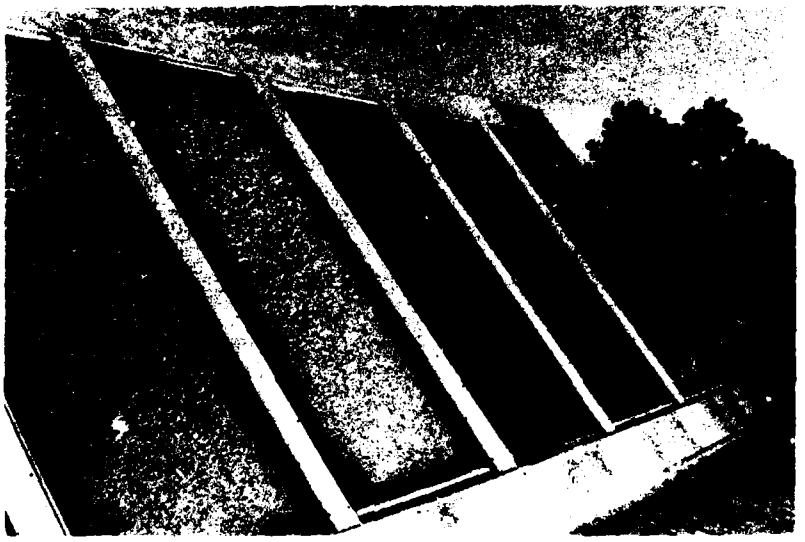


Figure 5.16 Roof Array Ice Cover

5.4 Solar Collectors

The solar collectors utilized were commercially manufactured flat plate collectors as opposed to the focusing parabolic variety. In addition, within the category of flat plate, the collectors used were considered to be of the high performance type. In this type, the working fluid is pumped under a hydrostatic head through conduits that are an integral part of the collector surface rather than being allowed to randomly flow across the collector surface under the influence of gravity.

Earlier in the USAFA Solar Energy Program, some experience was gained in the fabrication of both flat plate and parabolic solar collectors via cadet design and independent studies courses. Nevertheless, it was decided to use commercially manufactured collectors in the belief that the experience gained would have more Air Force-wide application.

The selection of the commercial solar collector was made in the spring of 1975. It was one of the first design decisions made as it had direct impact on the remainder of the facility design.

In the selection of a collector, a water media collector system was chosen over an air media collector system for the following reasons:

a. an air system would require the retrofitting of large quantities of supply and return duct work. Because it is the intention to return the Solar Test House to its original condition at the end of the project's test and evaluation phase in FY 78, this modification would not be cost effective;

b. an air system, if it used a crushed rock bed which is conventionally done, would require a sizeable storage space. In a retrofit project such as this, available space is severely limited;

c. an air system (unless used on conjunction with a heat pump) is not suitable for air conditioning because of the lower temperature generated. Because of the many potential applications for solar air conditioning in the Air Force, systems not supporting this should not be pursued.

In the spring of 1975, as compared to present, the number of commercially available solar collectors to select from was minimal. In reviewing the collectors that were available, timely selection was narrowed down to two different types of collectors, a copper-based unit and an aluminum-based unit. The comparative features of these two collectors are shown in Table 5.1. In reviewing these features, the copper-based solar collector was favored for the following reasons:

a. copper absorption surfaces have significantly less corrosion potential than similar aluminum surfaces with respect to water/ethylene-glycol mixtures;

b. copper is a more efficient thermal collection and transfer material than aluminum;

c. the copper-based collector had a per square foot cost less than the aluminum-based collector;

d. logistically, the copper-based collector could be obtained more readily. Because the collectors were to be Government furnished

Table 5.1 Comparison of Modular Solar Collector Features

PARAMETER	ALUMINUM BASE	COPPER BASE
1. Dimensions (Surface Area)	36" x 78" x 5" (19.5 SF)	36" x 78" x 3" (19.5 SF)
2. Weight per Panel (Unit Weight)	95 lbs (4.9 lbs/SF)	140 lbs (7.2 lbs/SF)
3. Cost per Panel	$162 ($8.31/SF)	$160 ($8.21/SF)
4. Delivery Time	4 to 6 weeks	1 to 2 weeks
5. Glazing	Double 1/8" tempered	Double 1/8" tempered
6. Collector Specifications		
a. Material	Aluminum	Copper
b. Absorbing Surface	Duracron Flat Black Coating	Nextrel Black Paint Surface
c. Thickness	0.060"	0.016"
d. Construction Type	Roll Bond	Laminated
e. Frame	Aluminum/Stainless Steel	Aluminum
f. Working Fluid	Water & Ethylene-glycol	Water & Ethylene-glycol
g. Flow Rates	0.2 to 0.5 gpm/panel (0.010 to 0.026 gpm/SF	1.5 to 6.0 gpm/panel (0.08 to 0.3 gpm/SF)
h. Insulation	2½" Fiberglass	3½" Fiberglass
i. Plumbing Line	Aluminum	Copper
j. Plumbing Line Accessibility	From the Back	From the sides, top and bottom via headers with access from the front

material for the construction contract, they were required to be on base prior to the Government initiating a contract;

e. the plumbing lines on the copper-based collectors were standard copper plumbing lines as opposed to aluminum on the aluminum-based collectors, thus facilitating installation in the field using common shop skills.

Accordingly, modular copper-based flat plate collectors, commercially manufactured by Revere Copper and Brass, were selected and used for this project. Figure 5.17, which was included in the contract construction drawings to acquaint the potential contractors with these solar collectors, illustrates their details.

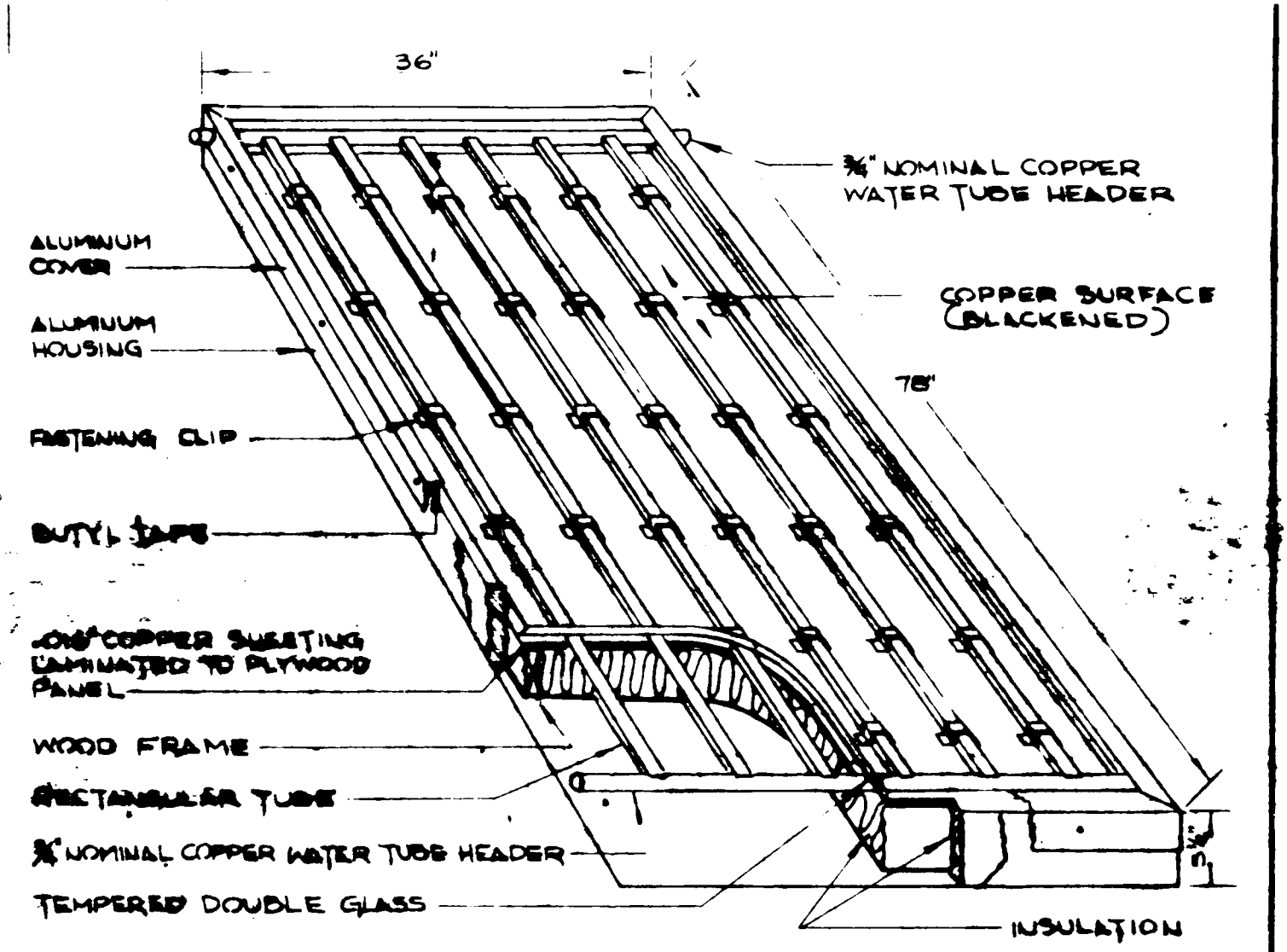
After the solar collectors had been selected, design emphasis shifted to proper flow configuration with each array. The three plumbing configuration choices were:

a. parallel

b. series

c. parallel/series combination

It was believed that an all-parallel system would require excessive pumping rates and an all-series system would result in very high temperatures at the last collector, which could lead to working fluid vaporization and result in low operating efficiency. However, a parallel/series plumbing configuration was used to obtain maximum thermal gain at minimum expenditure of mechanical energy. This configuration is shown in the as-built drawings in Appendix C.



DETAIL

MODULAR SOLAR COLLECTOR

Figure 5.1

During the construction phase and the test and evaluation phase to date, some major lessons associated with the solar collectors have been learned.

As mentioned in the previous section, if the solar collectors are left uncovered when not being used, superheating and some outgassing of the collector surface will cause condensation on the inner glazing surface. This phenomenon lowers the collector performance by reflecting some incident solar radiation in the early morning and later afternoon.

A more critical problem encountered during the system start-up was vapor locking. The vertical multipath design of the solar collectors (since replaced by the manufacturer with a sinusoidal path design), in conjunction with the parallel/series plumbing configuration, created an ideal environment for vapor locking. Air or working fluid vapor that collects in any portion of a solar collector allows that area to heat up and vaporize additional working fluid. This event forces the flow of the working fluid through other collection circuit paths. Eventually, high flow rates across small collector surface areas develop and elevated pressures are encountered. If the pressure becomes large enough, pressure relief valves, necessary to protect the solar collectors, will be activated and purge the collection system of the working fluid.

During initial start-up, efforts were made to charge the system with the working fluid during daylight hours. This proved unsuccessful because of the ambient heat that was already present in the system. After much trial and error, the system was successfully charged in the early morning hours before the system would heat up. In this regard,

the following minor plumbing modifications were made to assist in the operations:

a. replacing the 30 psig pressure relief valves;

b. removing the air vents on the individual solar collectors. Due to apparent high thermal stress conditions brought on by a large diurnal temperature differential often in excess of 200°F, the air vents allowed air to enter the system at night as it cooled;

c. the addition of some additional gate valves on the ends of all header pipes to allow for fluid bleeding during charging and thus the elimination of air pockets from the system.

These mechanical changes, in conjunction with the use of a low speed pump, and careful adjustment of the balancing cocks on the flow network, led to successful charging of the system and the elimination of the vapor locking problem.

Another problem encountered with the solar collectors during the construction phase was spacing. Spacing requirements depend upon the plumbing configuration desired, and the brand of collector utilized. The more piping required to connect the solar collectors in a specified plumbing configuration, the greater is the space required between the solar collectors and thus the greater is the non-productive area of the array surface. Some solar collectors currently available are plumbed from the rear and do not require extensive surface spacing. However, they do require array access. Additionally, it was noted that exterior dimensions provided by the manufacturer are only approximate and sufficient tolerance should be provided to allow for installation in the field.

None of the solar collectors were broken or damaged during the construction phase nor during the test and evaluation phase to date. Although the exterior surfaces do collect dust, this does not appear to affect their performance. Precipitation cleans the surface. No erosion of the collector surface has been observed.

5.5 Thermal Storage Tank

Due to the diurnal nature of the sun and the unpredictability of weather, a thermal storage system is required in conjunction with any solar heating system. Potential storage containers for a water media system include steel, fiberglass and concrete tanks which can be located either above or below grade.

The selection of a thermal storage tank for this project was based largely on cost and the application of the results to large-scale retrofitting of Air Force family housing units.

Based on cost alone, a reinforced concrete tank appeared to be an ideal choice. At approximately 15 to 20 percent of the cost of a comparable steel or fiberglass tank, a concrete tank could, in theory, hold almost 20 percent more thermal energy than a steel or fiberglass tank of equal volume because of the additional thermal storage provided by its concrete mass. In addition, on a large-scale retrofit basis, concrete tanks could be fabricated at the construction site. A reduction in cost may also be realized because of the ability of the lid to be poured in the configuration necessary for the associated plumbing.

A 2500-gallon concrete storage tank was selected for this project. This tank was the largest "monolithically" poured concrete tank available from local sources and is schematically illustrated in Figure 5.18. The tank was placed below grade adjacent to the foundation of the Solar Test House for aesthetic considerations and the

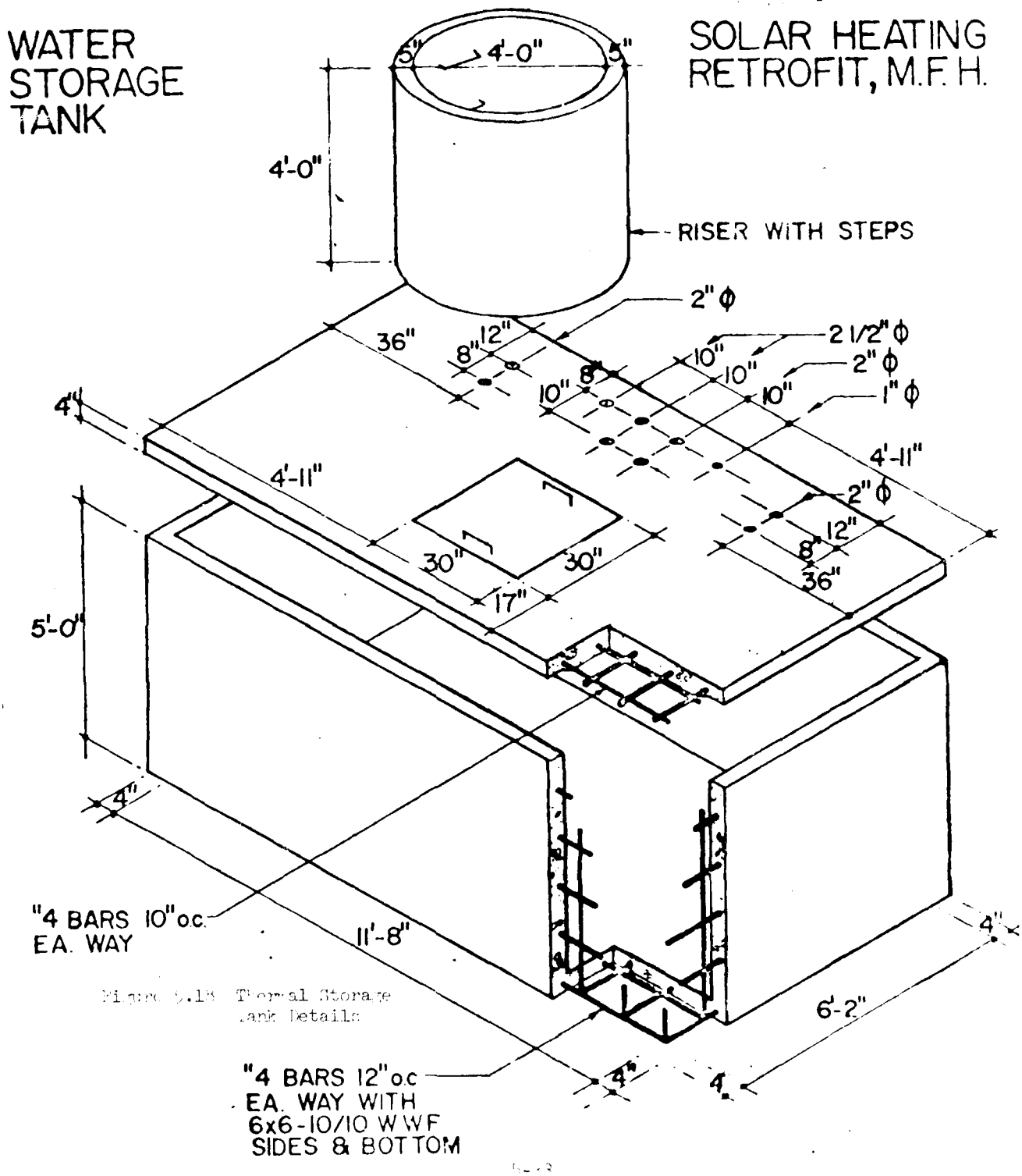


Figure 5.18 Thermal Storage Tank Details

benefit of the added insulation that would be provided by the warmer sub-frost line soil environment. Other energy conservation procedures involved insulating the tank sides and top with two one-inch overlapping layers of polyurethane sheets which were attached with hot asphaltic mix.

Some special care had to be taken during the placement of the concrete thermal storage tank. The subgrade had to be of a porous nature and as level as possible to prevent excessive stresses and cracking in the tank. (See Figures 5.19 through 5-22.)

During the initial operation of the thermal storage tank, the water level in the tank continually decreased as is illustrated in Figures 5.23 and 5.24. These observations were alarming as a definite uniform loss pattern was occurring. Possible sources of leakage were thought to be either loss through the concrete walls via cracking or vaporization through the manhole access lid. This uniform water loss was occurring at a rate of approximately 0.55 inch per day (one gallon per hour) and represented an approximate thermal loss of 600 Btu/Hr.

In late December, the thermal storage tank was pumped out to allow a plumbing crew access to the tank in order to make a plumbing modification (change the location of the foot valve on the domestic hot water pre-heat system). To prevent the loss of over 2300 gallons of heated water, two members of the Air Force Academy Fire Department pumped the heated water (approximately 100°F) out of the tank and stored it in a heated garage until it was needed for refill a few hours later. This operation is shown in Figure 5-25.

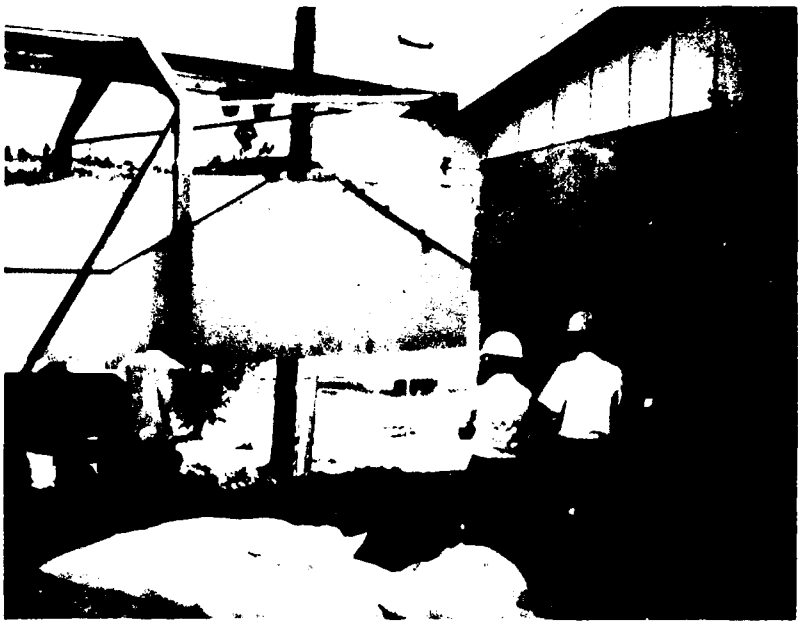


Figure 5.19 Thermal Storage Tank Being Lowered in Position

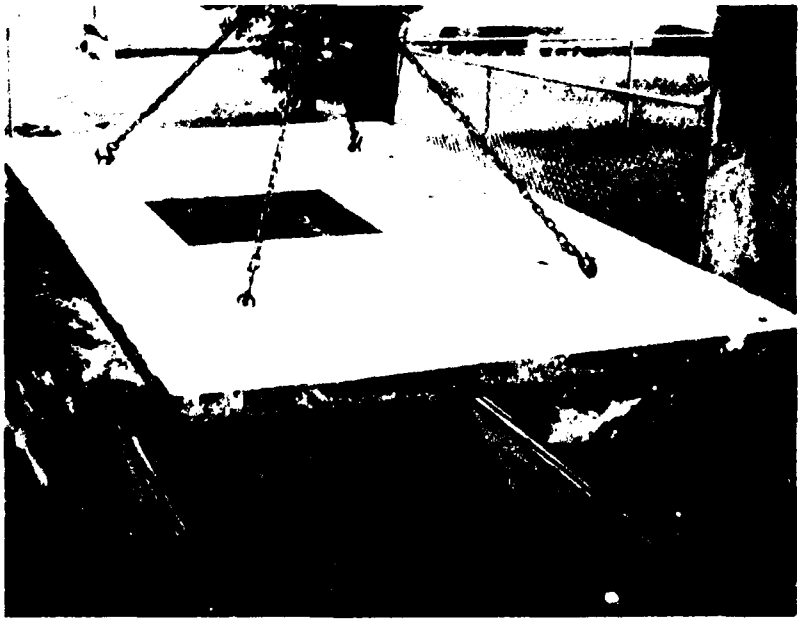


Figure 5.20 Thermal Storage Tank Cover Being Installed

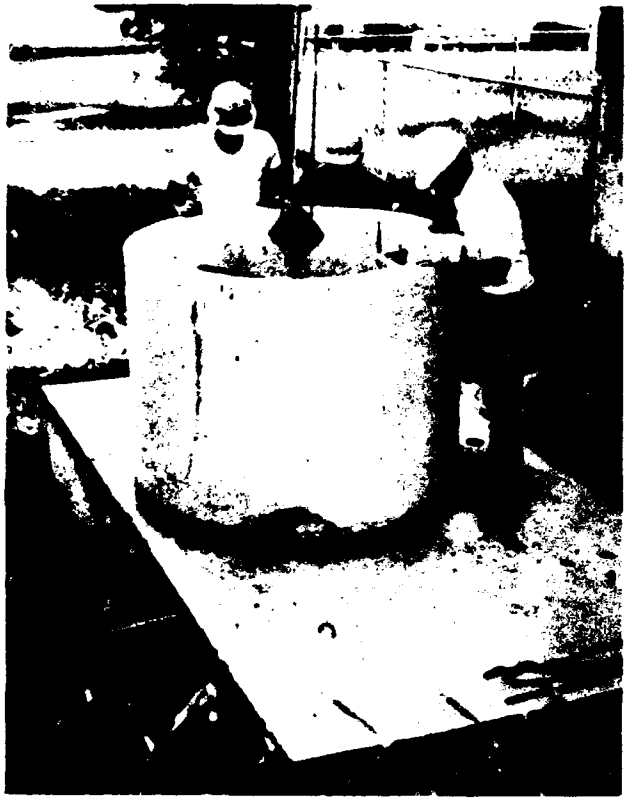


Figure 5.21 Thermal Storage Tank Manhole Being Lowered Into Position

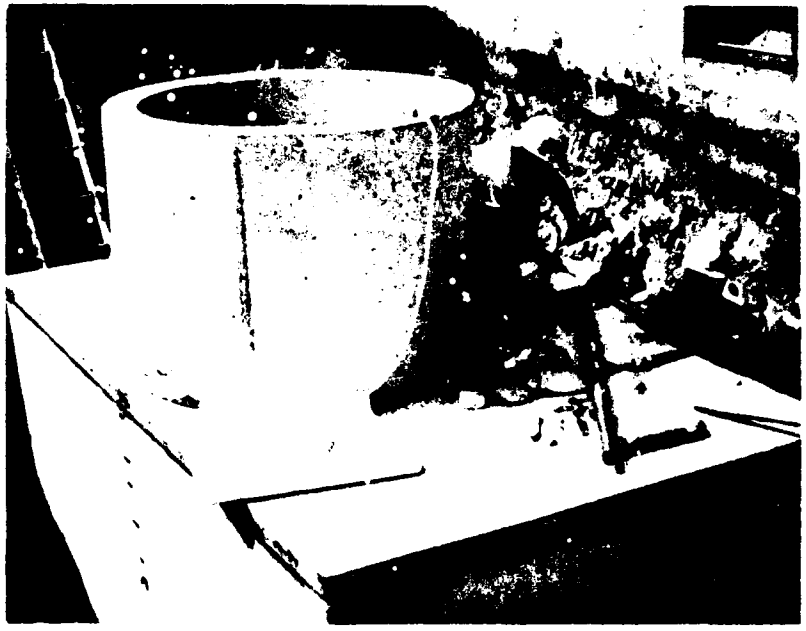
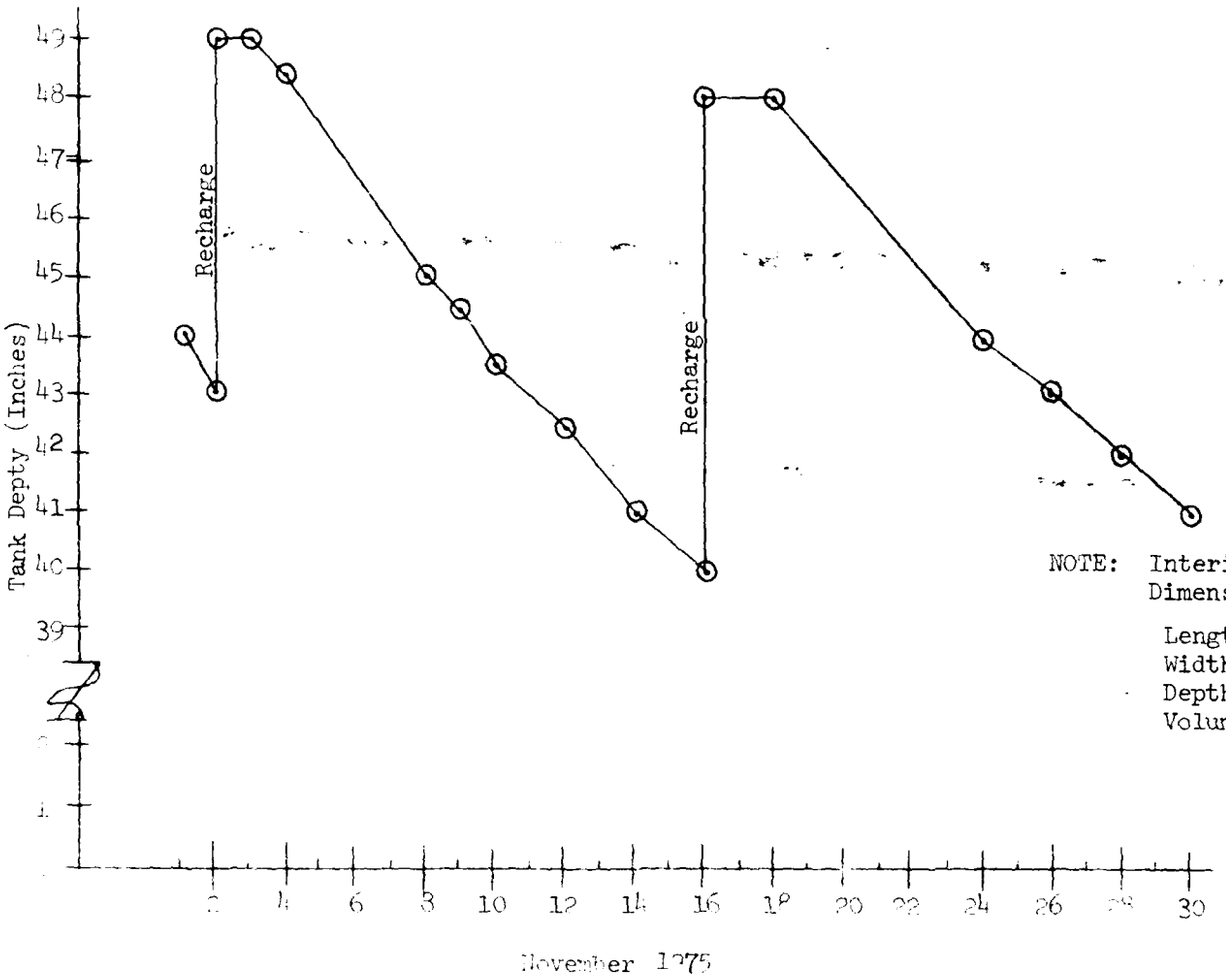


Figure 5.22 Plumbing Lines Being Installed in the Thermal Storage Tank

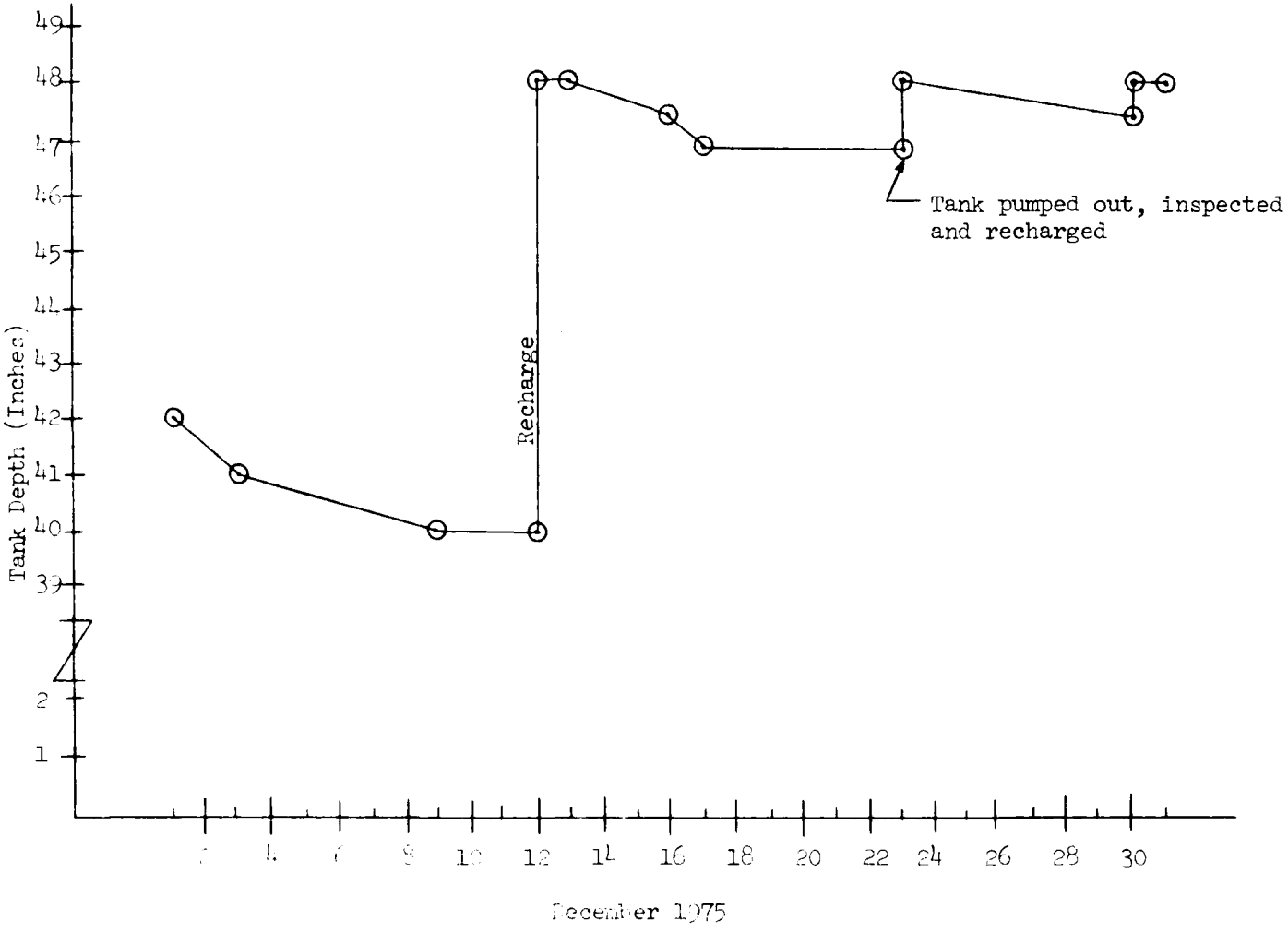
Figure 5.23 Changes in Depth of Water in Thermal Storage Tank



NOTE: Interior Storage Tank Dimensions are:

Length = 11' 8"
Width = 6' 2"
Depth = 4' 4"
Volume = 312 ft^3
2340 gal
19,448 lbs

Figure 5.24 Changes in Depth of Water in Thermal Storage Tank



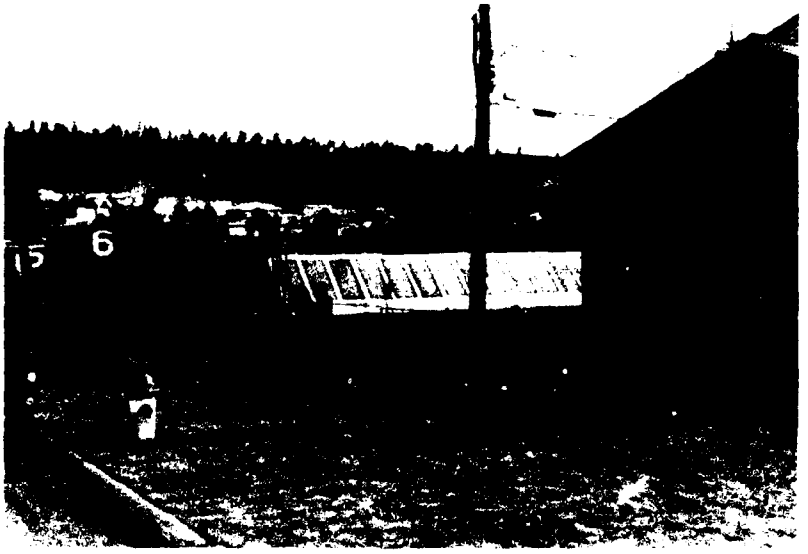


Figure 5.25 Pumping Out the Thermal Storage Tank (23 December 1975)

This operation provided the opportunity to visually inspect the inside of the tank. The results of this inspection were:

a. there were no visible cracks in the concrete walls;

b. the concrete surface had slightly eroded, exposing some "honey combing" which showed a somewhat porous aggregate mix.

c. the heat exchangers had a slight coating of "suspect" calcium carbonate and had some corrosion deposits as well.

d. the galvanized pipe and fittings were substantially corroded whereas the copper was not.

The thermal storage tank was initially filled with ambient tap water of a temperature of approximately 50°F. The adjoining soil temperature was approximately 70°F. During initial system operation, the temperature in the tank ranged from 100°F to 140°F with 170°F being experienced once. The water chemistry characteristics of the ambient water are reported in Table 5.2 for November 1975. The results of these observations may be summarized as follows:

a. The pH drastically increased. The alkalinity changed species as a result from bicarbonate to a carbonate/hydroxide mix.

b. The hardness decreased. This at first appeared to be a dichotomy but the water temperature rose considerably in November. This would have the effect of lowering the calcium carbonate/calcium hydroxide solubility product and induce precipitation.

c. The dissolved oxygen level remained substantially constant and essentially at saturated levels. It appears that there is no microbiological activity on the basis of this and the high pH.

In summary, it appears that the high temperature ambient tap water reacted with the fresh concrete and leached out some of the lime from the cement. These characteristics have remained stable since. This water does not circulate through the solar collectors. A 50 percent mixture of water and ethylene-glycol is pumped through the solar collectors and discharges the thermal energy gained to this water via heat exchangers placed in the tank.

Concerned about this water loss, an investigative effort during the Spring 1976 Semester was accomplished to examine the

Table 5.1 Summary of Water Sampling Results of the Thermal Storage Tank

PARAMETER	AMBIENT TAP WATER	2 NOV 1975	10 NOV 1975	17 NOV 1975	24 NOV 1975	23 DEC 1975
pH	7.8	11.0	11.1	11.0	10.8	10.6
D.O. (mg/l)	11.2	6.0	5.0	5.3	4.2	N/A
Turbidity (JTU)	0.5	1.3	1.0	3.8	2.3	7.5
Alkalinity (mg/l as $CaCO_3$)						
Total	38.0	119	98	99	77	78
OH^-	None	69	62	53	35	22
$CO_3^=$	None	50	36	46	42	56
HCO_3^-	38	None	None	None	None	None
Hardness (mg/l as $CaCO_3$)						
Total	129	147	76	52	59	77
Ca^{++}	56 (0.434)	47 (0.320)	38 (0.500)	45 (0.865)	31 (0.525)	19
Copper (mg/l)	Trace	0.50	0.28	0.20	0.80	0.80
Iron (mg/l)	Trace	0.05	0.05	0.05	Trace	Trace

effects of thermal stress on concrete tanks. In this investigation, a series of geometrically scaled reinforced tanks were constructed in different configurations and then subjected to thermal stress loadings. Such an experimental tank is shown in Figure 5.26.

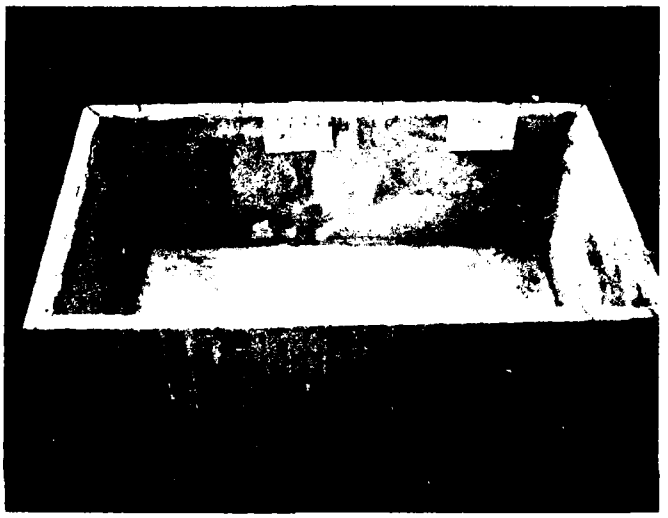


Figure 5.26 Model of Thermal Storage Tank

This investigation demonstrated that:

a. thermal stresses cause cracking in both the non-reinforced and the reinforced concrete tanks;

b. seepage from reinforced tanks is controlled and continuous, but slow (see Figure 5.27);

c. special waterproof coatings hold up well under thermal flexing (see Refernece 5);

d. a heavy, well distributed steel reinforcement pattern that provides for continuity at high stress points, such as the

corners of rectangular tanks, should be used;

e. reinforcing steel in both faces and in both directions in the walls should be used because of the flexure involved.

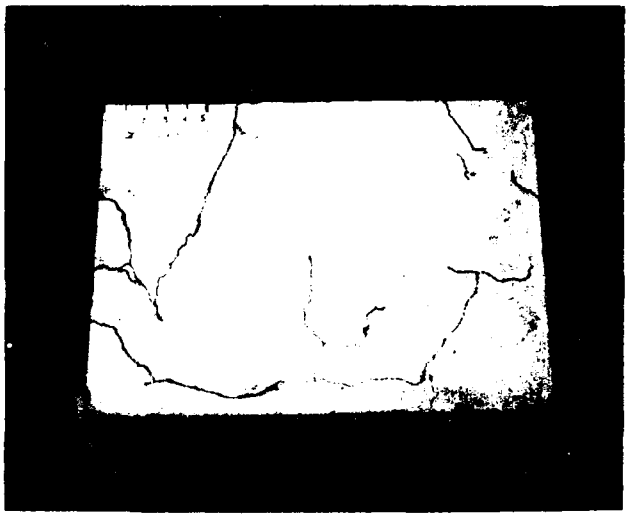


Figure 5.27 Thermal Stress Cracking Pattern

The cracking shown in Figures 5.26 and 5.27 has been highlighted with a felt tipped marker to make them more photographically visible. Typically, under both the hydrostatic stress and thermal stress (water temperature 192°F and the ambient air temperature 65°F), the crack spacing so propagated would be approximately 0.0001 inch; i.e., hair line. The concrete used had a seven-day strength between 3000 and 4000 pounds per square inch (psi). Type III high early-strength cement was used without additives. No course aggregate was used because of the narrow control dimensions of the wall thickness. The aggregate thus used consisted of sand

that would pass the number four sieve. Reinforcing was accomplished with 0.154-inch diameter steel wire with an approximate tensile strength of 1300 pounds (70,000 psi).

In conclusion, the successful long-term application of reinforced concrete thermal storage tanks for solar energy systems can result in a substantial decrease in capital costs. On the basis of the experience gained with such a concrete tank in this project, leaking appears to be a definite problem. However, after pumping out the tank for maintenance and inspection and subsequent refilling, the water loss was decreases to only two inches depth over a six-month period. An investigation into why this occurred has not started. In the future, rather than using a rectangular tank, a right circular cylinder tank may prove more beneficial because it eliminates serious stress concentrations that are possible in 90° corners.

5.6 Supporting Mechanical Equipment

Several types of heat exchangers were incorporated into the space heating and domestic hot water preheating systems. Because of the freezing temperatures encountered at the Air Force Academy, heat exchangers were installed in the thermal storage tank for both the ground and roof array loops. In so doing, a small amount of thermodynamic efficiency was forfeited in favor of a material savings in ethylene-glycol of over 1100 gallons. Moreover, the environmental problem of the potential hazardous material spill was negated. Thermally activated, self-draining systems were considered but were not believed to be fully reliable. These heat exchangers, manufactured by Tranter Platecoil, are of the flat steel plate type with serpentine fluid paths. These heat exchangers were plumbed vertically, two per array loop, as shown in the as-built drawings in Appendix C. The installation of one of these heat exchangers in the thermal storage tank is shown in Figure 5.28.

A Trane Climate Changer multirow aluminum fin heat exchanger with a 1500 cubic feet per minute (cfm) blower was installed in the furnace supply air plenum. This unit is shown in Figure 5.29.

A Bell and Gossett shell and tube heat exchanger was installed in the domestic hot water preheat loop. The primary hot water tank make-up line from the street main was directed through the tube, while the solar-heated water from the thermal storage tank was pumped through the shell. This heat exchanger is kept charged by both a flow switch in the make-up line and an aquastat in the shell.

Figure 5.28 Thermal Storage Tank Heat Exchanger

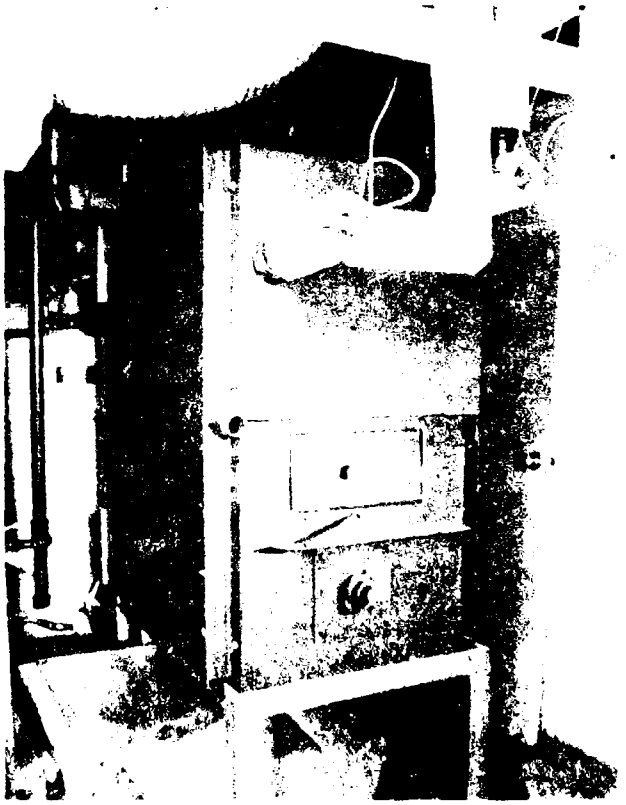


Figure 5.29 Furnace Supply Air Plenum Heat Exchanger

Both of the pump activator loops are governed by an electrical timer which shuts off power to the preheat loop from 2200 hours to 0500 hours to conserve electrical energy. Typically, this heat exchanger loop preheats the domestic water to 100°F and the natural gas-fired hot water heater heats the water the rest of the way to 130°F. The preheat temperature level is a variable that may be changed. It is dependent upon the temperature of the water in the thermal storage tank.

Four Bell and Gossett single-flow rate (constant speed) pumps were used to support the solar energy heating system. These pumps and other supporting mechanical equipment are shown in Figure 5.30.

Figure 5.30 Solar Energy System Mechanical Equipment

The pumps for the heat exchanger in the furnace supply air plenum and the domestic hot water preheat loop are rated at 1/6 horsepower. The pumps for the ground and roof array loops are rated at 1/2 horsepower. The flow rates through the ground and roof array loops are varied by a Honeywell modulating flow control valve as is shown in Figure 5.31. These valves are motor controlled and computer activated, the signals of which are based on programmable system temperature differentials. They provide a range of flow rates that vary from 2 to 16 gallons per minute (gpm).

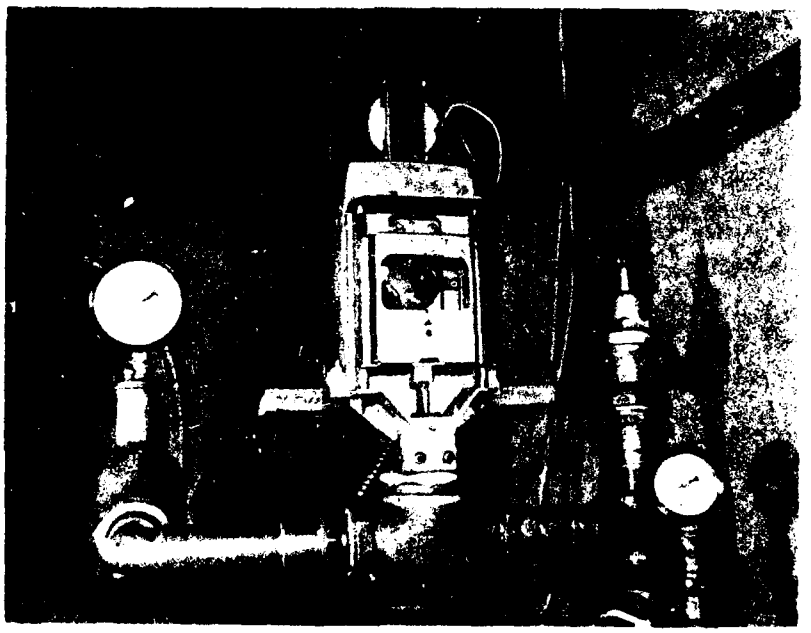


Figure 5.31 Modulating Flow Control Valve

Both the roof and ground array loops contain a Tyco brand diaphragm expansion tank with a float air bleeding valve and a 50 psig pressure relief valve. Normal operating pressures are approximately 15 psig to 20 psig. Substantially higher pressures can be experienced as the working fluid temperature rises under unusual conditions such as power outages.

All piping used consisted of type K and L seamless copper tubing. Where connections were required to equipment components of dissimilar materials, dielectric unions were used.

The selection of the types and quantities of insulation required to prevent heat loss in the various loops required serious consideration. Initially, all lines were designed to be completely insulated with sleeve type insulation. However, during the final design, it was realized that such a practice would result in an insulation cost in excess of $6000. Redesign resulted in the following being used:

a. powdered hydrophobic type for piping insulation to the ground array;

b. fiberglass split-sleeve type for piping insulation from the storage tank to the basement and in the basement;

c. foam rubber (Armaflex) type insulation for exposed piping to the roof array;

d. all piping within both the roof and ground arrays would remain uninsulated.

During the operation of the system, it has been determined that filling the array piping raceways with poured-in fiberglass insulation should be further investigated.

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CHAPTER 6

INSTRUMENTATION AND CONTROL SYSTEM

6.1 Introduction

In support of the belief of Air Force Academy officials that the most gains to be made in solar energy applications lie in control theory rather than in solar collector technology, significant engineering efforts were directed at the instrumentation and control system (ICS). The objectives of this ICS were to identify all significant solar energy system operational and performance variables and thereby develop the necessary solar energy system control functions. To achieve these objectives, a completely flexible ICS was required and so developed.

To accurately determine which are the important variables in a solar energy system, both digital and analog data are required. The final configuration of the instrumentation system required for this project could not be completely anticipated at the beginning of the design phase. As additional knowledge of the solar heating system was gained, instrumentation requirements changed slightly. Accordingly, the ability to readily expand or change the instrumentation system was identified as necessary and was provided.

At the start of the project, the optimum control algorithm for the solar heating system was an unknown. The approach was to use the instrumentation system to develop the optimal control system. Thus,

a control system that could easily be changed or restructured was essential. Both the requirements for rapid change and flexibility were accomplished by using a microcomputer system as the central data gathering and control point. By selecting the necessary data sensors and interfacing these with the microcomputer, the data necessary to determine system performance was readily available.

System control was also accomplished by developing an appropriate program for the microcomputer. After the initial control algorithm was established and programmed, adjustments in system operation were made by changing computer "software" rather than "hardware." The process of developing the optimal control algorithm has been going on since system start-up. However, by being able to both observe system performance and make adjustments to system operational configurations on a real-time basis, the ability to optimize system control has been tremendously enhanced.

By observing the solar energy system performance over an appropriate period of time, the most significant system variables necessary to develop an optimum control system became readily available. The final criteria for the evaluation of these was "cost per unit of energy delivered."

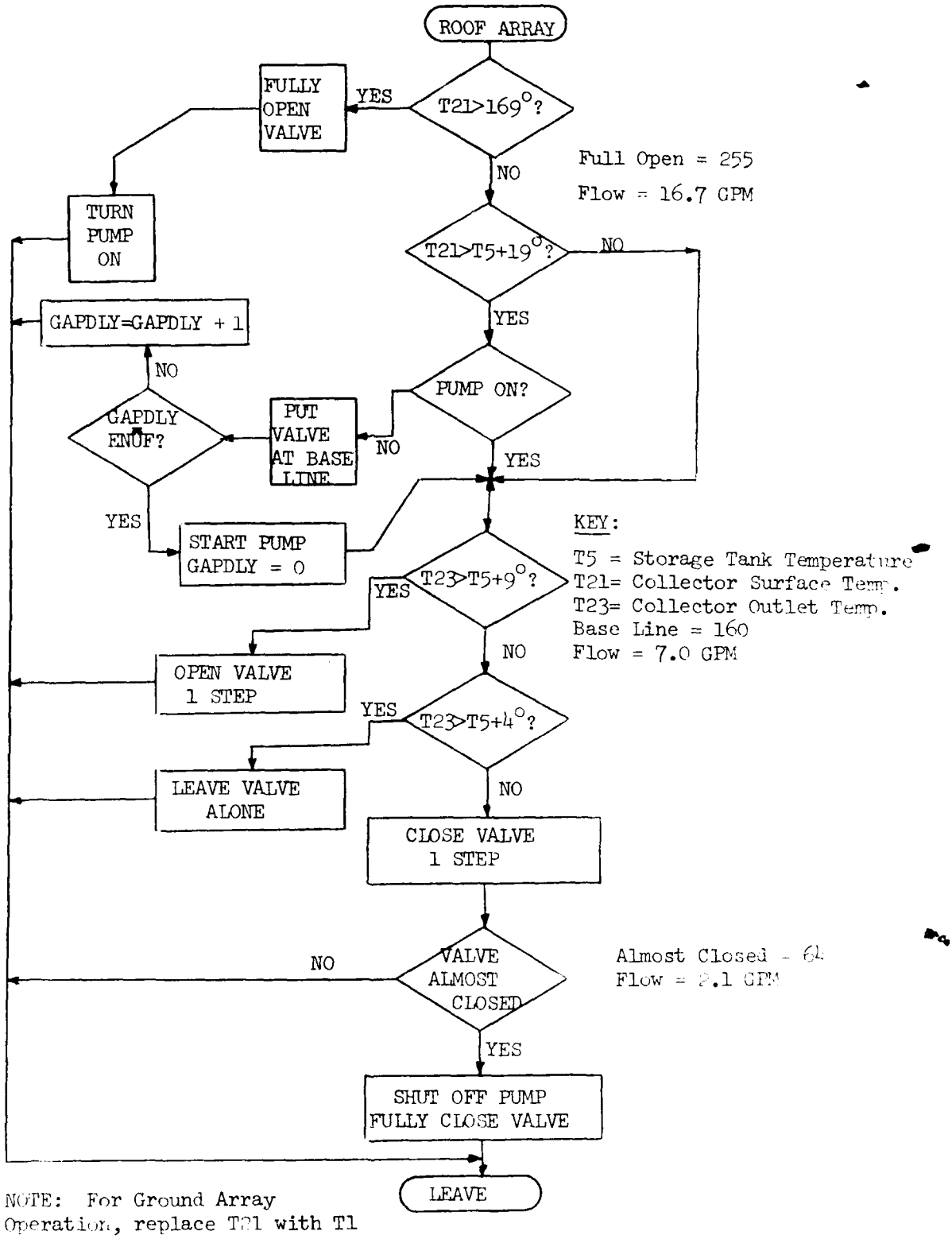
6.2 Solar Heating System Software

The solar energy system is composed of two major dynamic sub-systems - the collection cycle on the two arrays and the heating cycle. The control algorithms for these two sub-systems are shown in Figures 6-1 and 6-2. The ground array control is based on the same logic as the roof array, but its operation is completely separate. The microcomputer scans all system sensors and executes the control function every eight seconds. This execution rate is also a system variable. Again, it should be emphasized that these algorithms are implemented in software. If changes to the operation of either array or the heat coil are desired, then only reprogramming of the microcomputer is required. The ability to observe the effects of these changes on a real-time basis has been the key to evaluating the different operational schemes.

In developing the real-time task scheduler, two approaches were considered for the allocation of the computer central processing unit (CPU) to the tasks defined by the control algorithms. The first approach considered was to make the control task interrupt-driven; i.e., to initiate a control function whenever some external event or condition occurred. The second approach considered was to run the control process tasks in a preassigned order at preassigned rates, using delay and timing loops.

The second approach was considered to be easier to implement as well as less costly since interrupting generating and servicing circuits and programs are not required, and was thus adopted. Its flow chart is illustrated in Figure 6.3. A basic delay routine can be used

to do timed waits or control actions in mechanical or chemical systems where process changes are so slow that the majority of the control time is spent in delay loops. The control sub-program is executed every eight seconds as determined by the software counters. Printouts are done every 15 minutes, as determined by an external alternating current (a-c) line-operated digital clock connected to the micro-computer or every time a control function changes. Other various software sub-program flow charts are included in Appendix D.



NOTE: For Ground Array Operation, replace T21 with T1 and T23 with T3.

Figure 6.1 Control Algorithm-Arrays

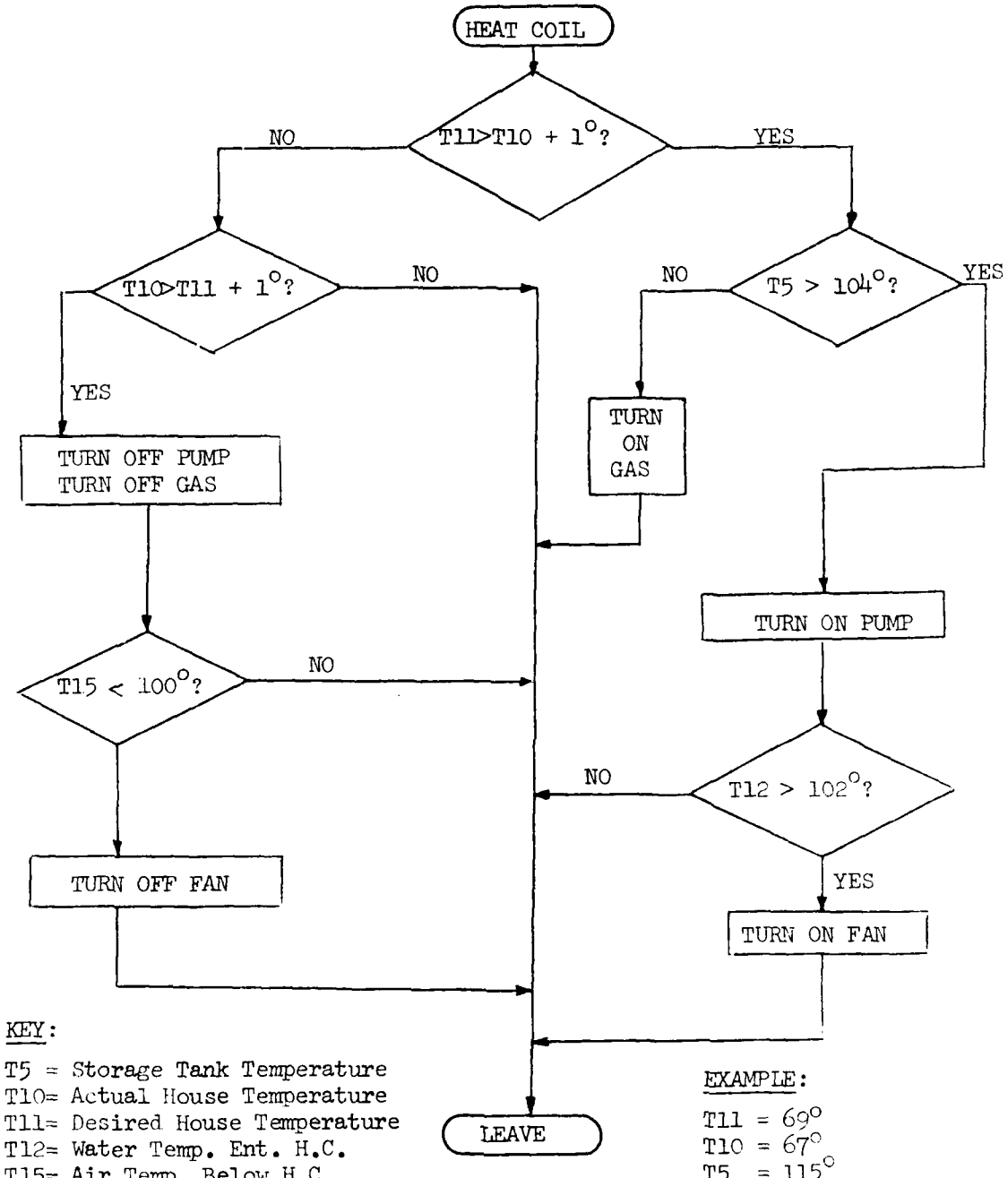


Figure 6.2 Control Algorithm - Heat Coil

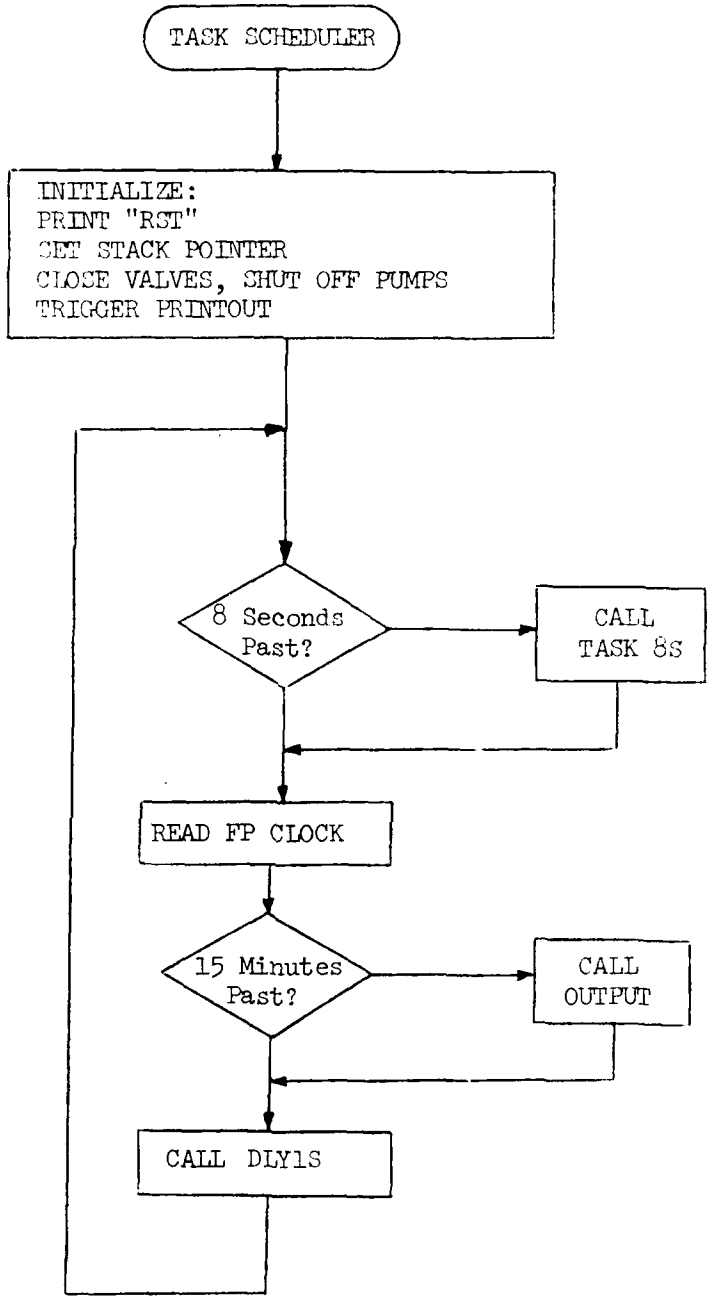


Figure 6.3 Control Algorithm - Task Scheduler

6.3 Solar Heating System Hardware

The solar energy system hardware is composed of a number of components, the major ones being the:

a. microcomputer

b. status display console

c. teletype

d. control outputs

These components are illustrated in Figure 6.4 and described in further detail on the following pages.

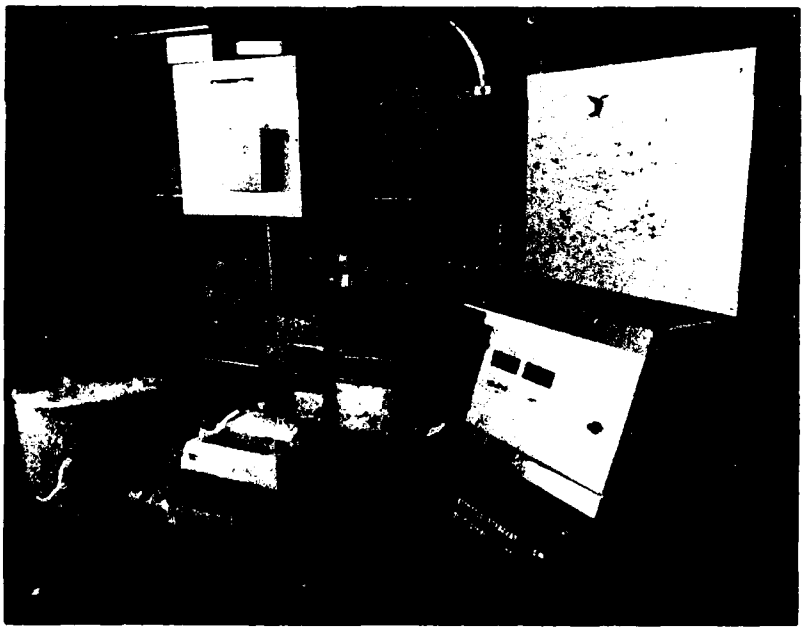


Figure 6.4 ICS Hardware in Mechanical Room

The system microcomputer, an Intellec 8/80, has three major sub-systems: the input/output ports (I/O), the central processing unit (CPU) and the memory. The basic computer has four each 8-bit inputs and outputs. Two additional IMM-81 I/O cards were added to expand the machine to 12 input/output ports. The CPU cycle time is approximately two microseconds per memory cycle and the CPU has eight internal registers, push-down stack and arithmetic, logic and control instructions. It can address 256 input and output ports and 65,000 words of memory. It also has over 8000 words of Read-Write-Memory (RWM) for temporary data storage. The memory used to store the control algorithm is Erasable, Field-Programmable Read-Only Memory (PROM). The microcomputer is also connected to a visual status display console provided for real-time observations of system operating configurations and selected system sensor points. The teletype provides for the permanent acquisition of the instrumentation system generated data. Various system hardware components are illustrated in Figures 6.5 through 6.12. Electronic schematic diagrams are included in Appendix F.

All systems control outputs and sensor inputs can be displayed on the status display console with light emitting diode (LED) lights to indicate on/off, the status of binary control functions, and the digital read-out of the sensors. The status display console has push-button switches that are mounted on a schematic diagram of the NAFA Solar Test House so that the status at any point in the system can be displayed in response to switch requests. The buttons are all connected to a priority encoder which the computer interrogates. If any switch is depressed, its encoded sequence number is read by the computer. The

Figure 6.5 Digitizer Card

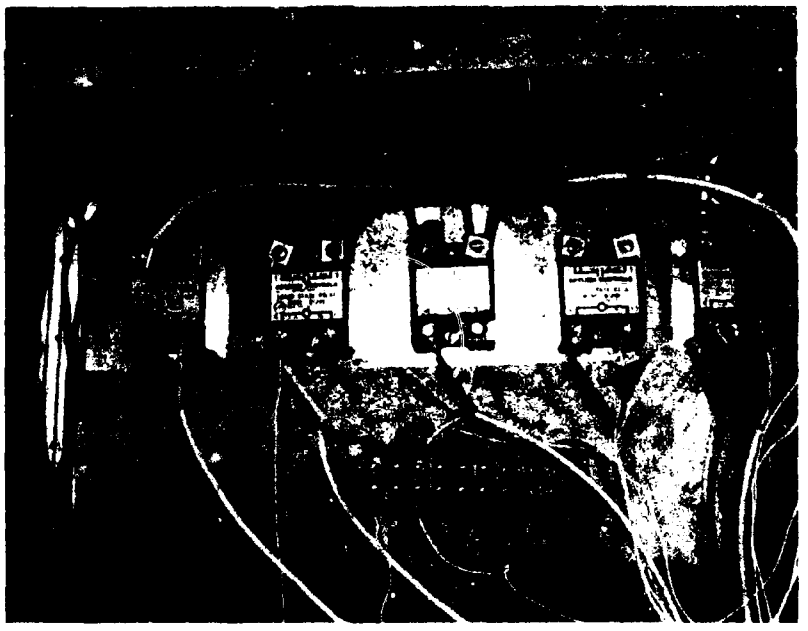


Figure 6.6 Power Control Box with Microcomputer Controlled Solid State Relays

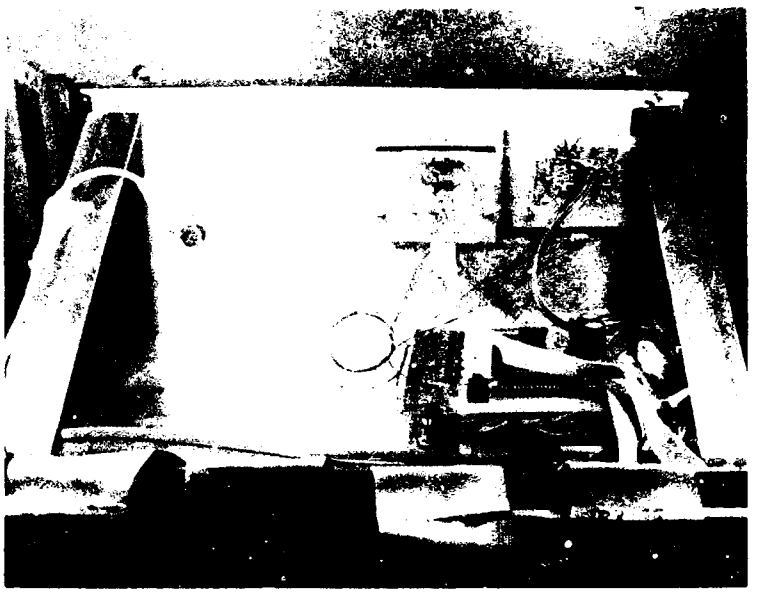


Figure 6.7 Top, Rear View of Microcomputer Chassis Rack Showing Digital Clock and Sensor Read-Out Units

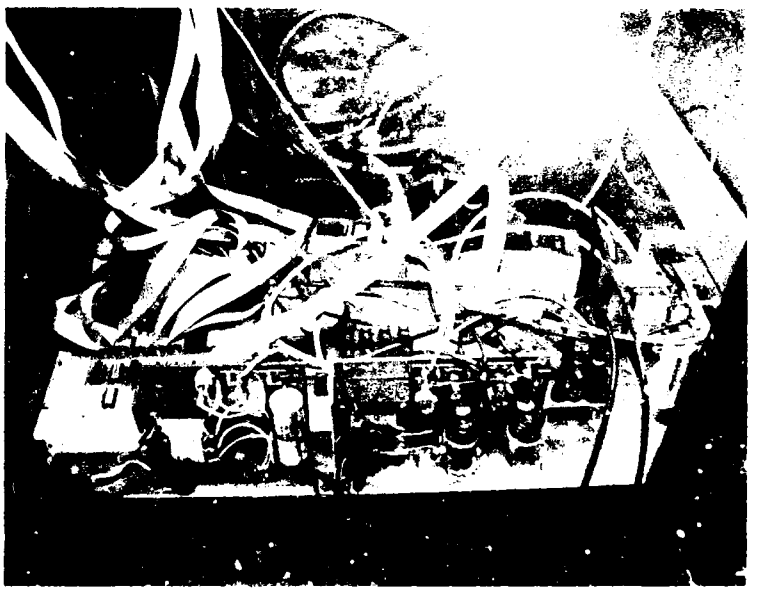


Figure 6.8 Front View of Microcomputer Chassis Cover Removed Showing the Analog Calibrator, Controller and Power

Figure 6.9 Rear View of Microcomputer

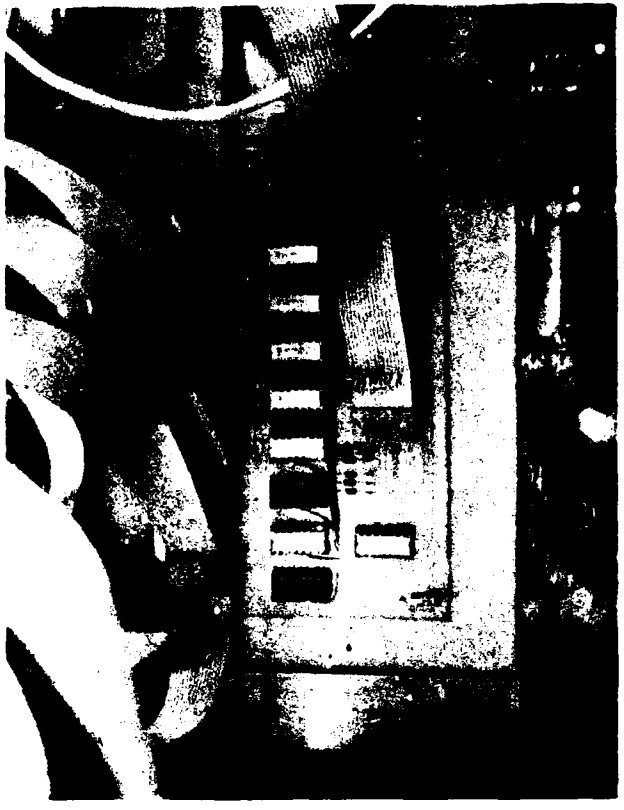


Figure 6.10 Analog Multiplexer

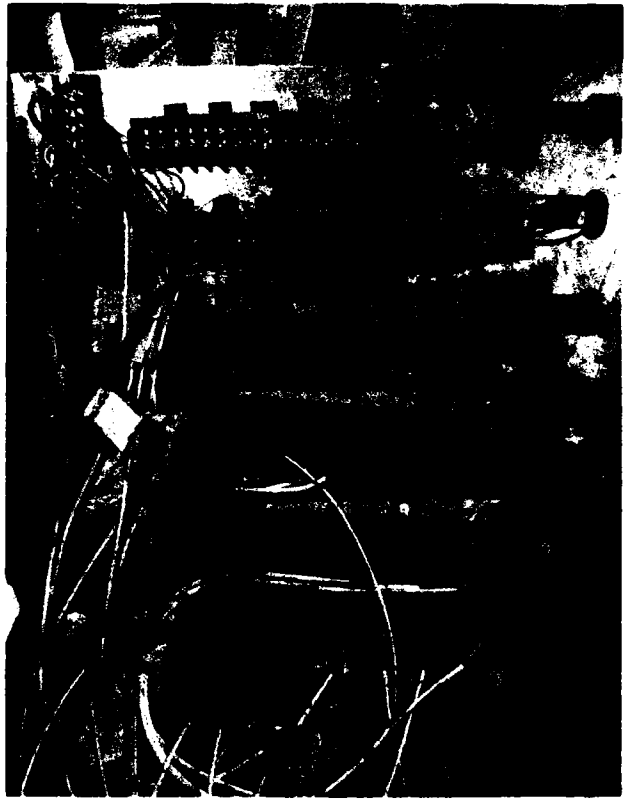


Figure 6.11 Sensor Termination Panel

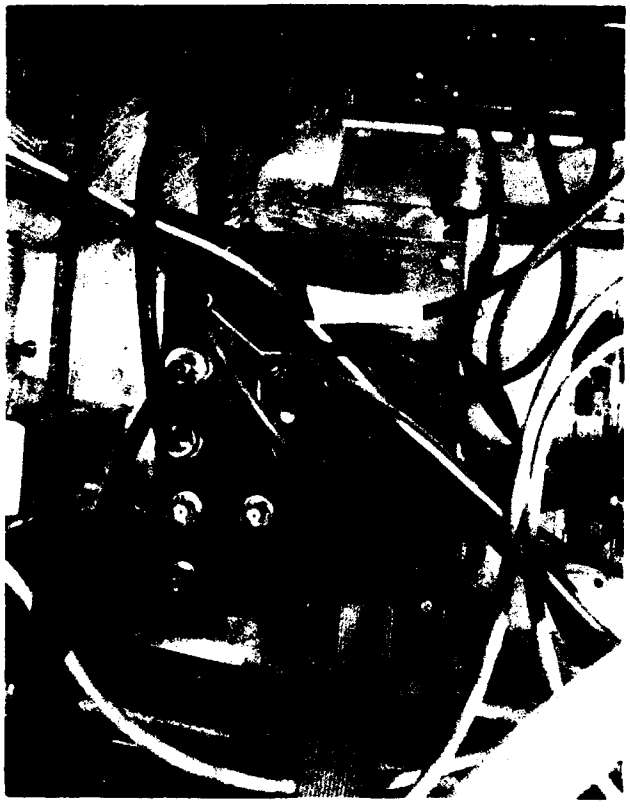


Figure 6.12 Remote House Controller (Solar Control House)

encoded number is, in turn, used as an index into a data table and on this request, the corresponding sensor value is output to a digital read-out. This status display console is illustrated in Figure 6.13.

Figure 6.13 Status Display Console

The teletype used is a model ASR-33 (automatic send/receive). This teletype records instrumentation system data on roll paper for immediate visual review and on heavy-duty black paper tape. It is read through a high-speed reader, transferred to magnetic tape for system off-line analysis, and permanent storage. The data sampling and data recording rates are system variables and can be changed to any appropriate rate for required data analysis. This teletype is shown in Figure 6.14.

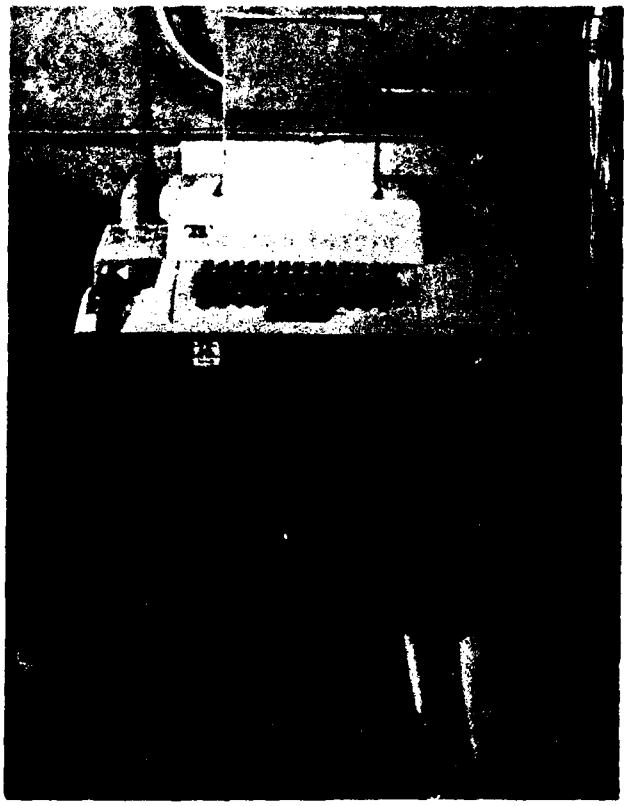


Figure 6.14 Teletype

A large number of control functions were implemented simply as on/off control. The standard interface for these was a low level TTL (transistor-transistor-logic) signal. If the device being controlled was electrically direct-current (d-c) powered, a transistor switch was used. Such a switch could not be used with a-c powered motors and inductive load switching because of potential hazards such as ground loop noise and electromagnetic interference. To overcome these problems, solid state relays with optical coupling between input and output circuits were used. This allowed the microcomputer logic-level

signals to directly control the switching. No derating was required for the inductive loads and switching was done only at the waveform zero crossing. For those devices which required a proportional analog control output, a standardized output interface was established as 0.0 to 2.0 ma d-c. This range was picked because of the availability of low cost digital to analog converters with this specification. In the case of the modulating valves, because they required a different control range, a special interface adapter had to be constructed. The electronic schematic for this is included in Appendix D.

6.4 General Considerations for Signal Acquisition

The first requirement of a computer-based instrumentation and control system is to sense and read into the computer the process parameters. In the ICS at the USAFA Solar Test House, a variety of sensors were required that provided a variety of electrical outputs.

The various sensor inputs to the multiplexer were standardized to be a d-c voltage in the range of 0 to 10 volts. Any sensor which generated non-standard electrical signals (pulse duration modulation or sinusoidal outputs) was interfaced to the system via an interface adapter which converted the unique signal to the standard 0 to 10 volts d-c required by the multiplexer. In this regard, two major problems involving data fan-in and common signal format were encountered and overcome.

The data fan-in problem was associated with how to monitor all the process variables associated with the ICS without providing individual analog to digital conversion and an I/O channel for each analog process parameter, thus avoiding the associated high costs. Because the sampling rate was not too great, it was possible to time-share the analog-to-digital converter (ADC) and computer I/O channel by the use of an analog multiplexer. Accordingly, such a multiplexer was designed to allow all the sensors to be read through a single input port using a common digitizer. The schematic for this multiplexer is included in Appendix D. The program outputs a sensor number. The multiplexer, in turn, connects the requested analog channel to the common digitizer, and the converted digital value is then input by the microcomputer. The total time for this process is approximately 0.2 milliseconds.

The analog multiplexer (AMUX) was constructed using digitally controlled MOS (metal oxide semiconductor field effect transistor) switches. Two cascaded ranks of 8-to-1 switches were used. This allowed any one of 64 analog signals to be accessed based on a 6-bit address word. The AMUX was constructed with latch-proof overvoltage protected MOS switches to maximize the mean time between failures. Because the digitizer used required a d-c signal in the range of 0 to 10 volts, the AMUX was designed to pass this same range. The microcomputer program provided the software interface by setting the multiplexer to each sensor, strobing the digitizer, and reading and storing the digitized value into the microcomputer.

The digitizer represents the bulk of the time delay in the sensor system since the analog switch requires 0.25 microseconds per a cycle. The constraint on the sampling process is that each sensor input is serviced at a rate no less than twice its highest frequency component. This is related to the number of channels (NCHAN) and to the highest frequency component in the analog signal, as shown below.

$$T_{switch} + T_{CPU} + T_{conv} \leq \frac{1}{2\, f_H\, NCHAN}$$

This system has proven to be well suited for the ICS. It has the potential to sample 40 to 1000 sensors per second.

Since the digitizer required 0 to 10 volts d-c, this was adopted as the system standard sensor interface and brought about a second problem of a common signal format. Sensors which generated non-standard electrical signals were interfaced to the system via interface adapters. Schematics for these are included in Appendix D.

6.5 Solar Radiation

The first requirement for any solar energy system evaluation is to determine what energy is available. There are various instruments available for this measurement of solar radiation (insolation); however, the most common instrument is the spectral pyranometer. This instrument measures total radiation intensity (beam and diffuse) on a plane. In as much as flat plate solar collectors use both beam and diffuse radiation, the choice of a spectral pyranometer was consistent with the application to this project. Accordingly, an Epply Precision Spectral Pyranometer was used.

This pyranometer provides an output signal that is proportional to the incident solar radiation intensity. The approximate range of this d-c voltage signal is from 0 to 12 millivolts, and in order to adapt this low signal level to the standard 0 to 10 volt d-c signal range used for digitizing, the signal was amplified by a X500 gain stage mounted in the pyranometer base. The schematic for the interface adapter is included in Appendix D. In order to determine the total energy availability, the pyranometer signal must be integrated with respect to time. Results of this operation will be presented in Chapter 7.

The pyranometer was mounted on a rotatable steel platform and then installed on the roof of the Solar Test House. The pyranometer was set in a horizontal plane, but it can be set at any horizontal angle to allow for the direct measurement of radiation received by a collector at any slope. The pyranometer, installed, is shown in Figure 6.15.

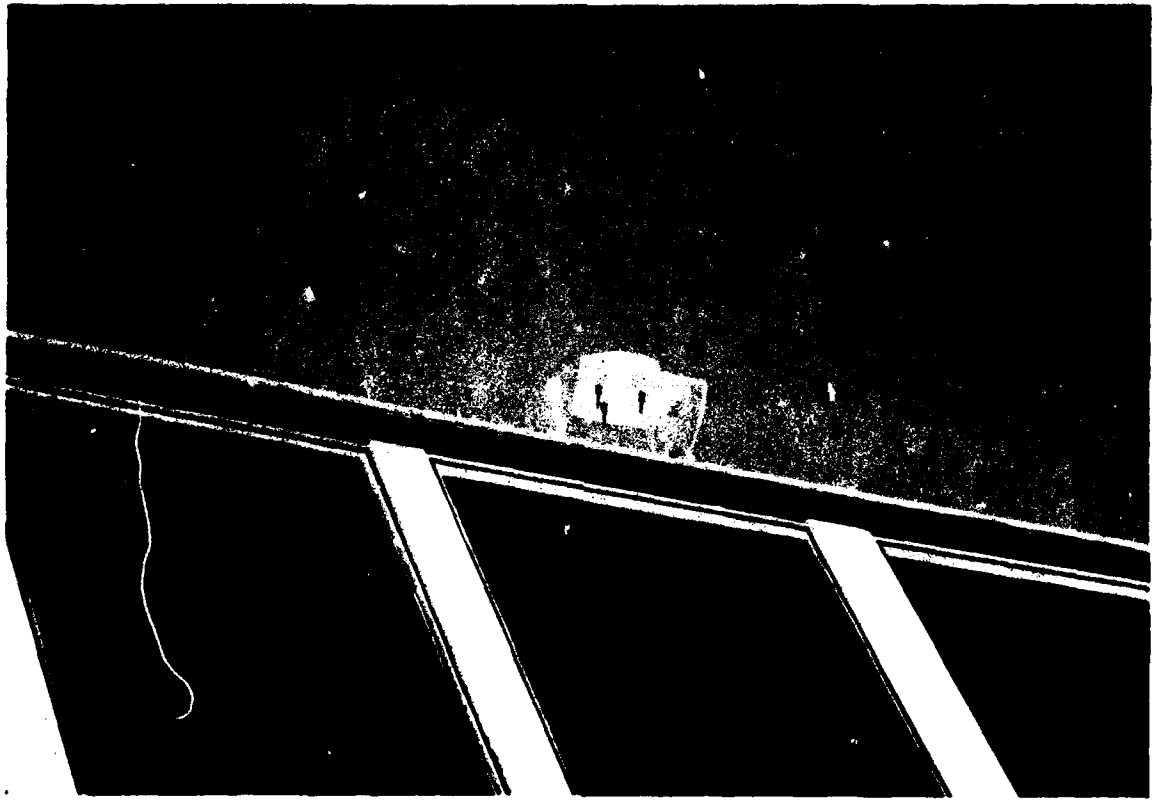


Figure 6.15 Pyranometer

6.6 Other Meteorological Monitoring Equipment

In addition to solar radiation information, the significant weather variables with respect to solar energy system performance appear to be wind speed, wind direction, temperature and humidity. This information is usually available for a general vicinity. However, to accurately determine the effects of these parameters on the performance of the solar energy system, it was necessary to measure these parameters at the site.

Accordingly, with the assistance of the United States Air Force's Air Weather Service of the Military Airlift Command, an AN/TMQ-15 wind measuring set and an AN/TMQ-20 temperature and dew-point measuring set were installed at the USAFA Solar Test House. Both of these tactical weather towers are standard inventory items. They are illustrated in Figures 6.16 and 6.17.

Both these instruments generated pulse-modulating output signals that were not compatible with the analog multiplexer and the digitizer. Consequently, a conversion scheme using a low-pass filter to extract the average value of the TMQ-15 signals was used as was similar circuitry for the TMQ-20 to provide the required standard 0 to 10 volt d-c interface. These schematics are included in Appendix D.

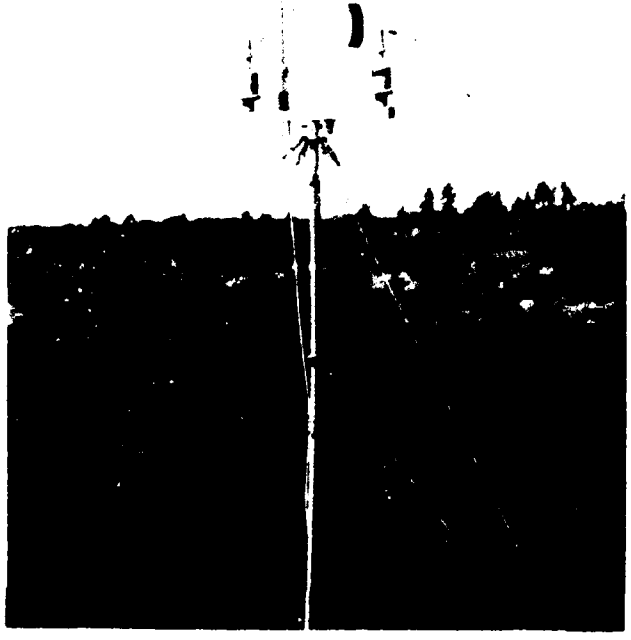


Figure 6.16 AN/TMQ-15 Wind Measuring Set

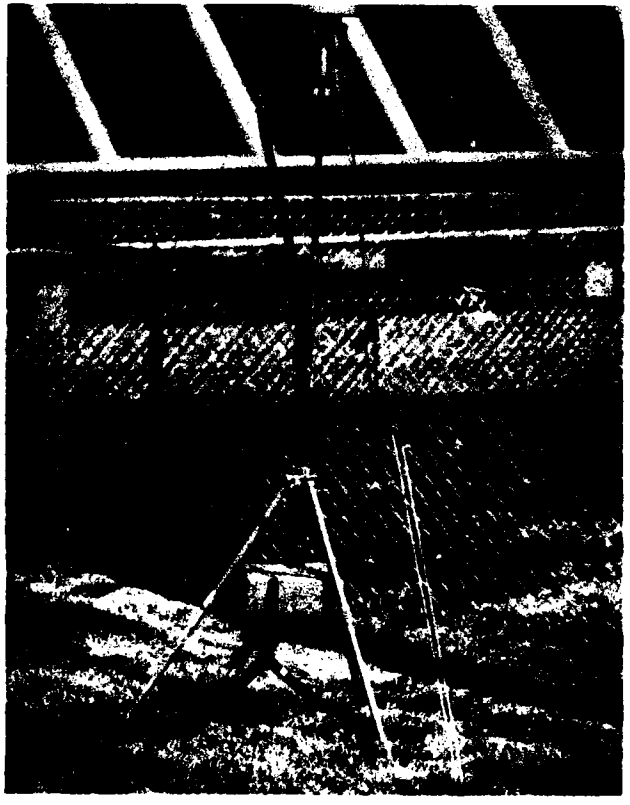


Figure 6.17 AN/TMQ-20 Temperature and Dew Point Measuring Set

6.7 Temperature Sensors

An accurate temperature sensing ability is a definite requirement for any thermal instrumentation and control system. In this regard, the entire solar energy system control process is based upon being able to evaluate specific system temperatures. A 5 to 10 percent error in temperature evaluation can lead to a similar loss in system energy collection efficiency. Temperature transducers manufactured by Relco Products, Inc., as shown in Figure 6.18, to measure air (dry) and working fluid (wet) temperatures were used.

Figure 6.18 Temperature Transducers
(Top - Dry, Bottom - Wet)

These temperature transducers use p-n semiconductor junctions to produce a linear voltage (to within $\pm$ 0.1%), with respect to temperature, and can be fabricated in accordance with sensitivity, zero point, and supply voltage specifications. Because the internal microcomputer representation is a binary 8-bit number in the range of 0 to 255, the temperature sensor sensitivity was chosen so that the digitized voltage number was exactly the same as the Fahrenheit temperature it sensed. This allowed for the maximum resolution and accuracy of temperature measurement consistent with single precision integer arithmetic with an 8-bit computer.

The temperature transducers require no interfacing with the analog multiplexer because their signal voltage output is in the standard range of 0 to 10 volts d-c. The power supply cable provides 15-volt power and is ground to the transducer. To minimize drift in the sensor output, a 0.2 percent line and load regulation is maintained on the 15-volt supply line.

The temperature transducers were installed in the Solar Test House and Control House as shown on the as-built drawings in Appendix C. The method of mounting the dry sensors is quite flexible. All that is required is for the transducer to be completely exposed to the air or to the surface of which the temperature is to be measured. No dry sensors have malfunctioned since their installation in October 1975. The wet sensors were mounted so they could be exposed directly to the working fluid. The conventional temperature well was not utilized due to the associated decrease in the response time of the transducer. Instead, the mounting device consisted of a brass plug with an outside

diameter equal to the pipe tee inside-diameter they were installed in. This brass plug was center drilled to accept a 5/16-inch female compression fitting. The brass plug was then installed in the pipe with a sweat fitting. The center of the compression fitting was drilled out to the outside diameter of the temperature transducer. Then, the compression fitting was tightened around the transducer and then installed in the brass plug. No leakage has been encountered or maintenance has been required for this mounting device. Some typical installations of these sensors are shown in Figures 6.19 and 6.20.

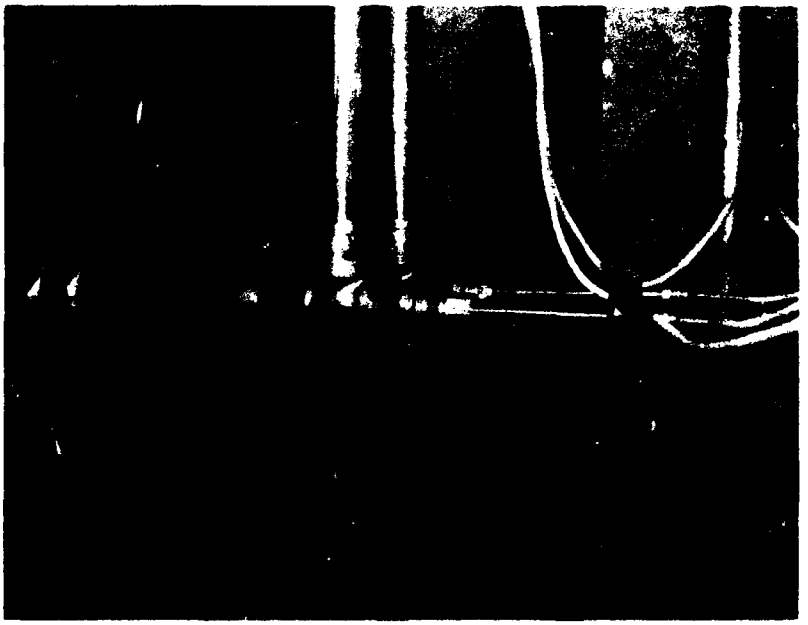


Figure 6.19 Wet Sensors Installed in Domestic Hot-Water Preheat Coil

Figure 6.20 Wet Sensors Installed in Roof Array Header Pipes

6.3 Flow Measurement

By combining temperature information with the fluid flow rates, the energy production capability of the solar heating system can be determined. To do this, the fluid flow rates through the following system components have to be known:

a. the solar collector loops

b. the preheat hot-water loop

c. the furnace heat-coil loop

The initial hardware used to measure the fluid flow rates were differential pressure devices. Meters were installed to induce non-uniform fluid flow. Pressure transducers were fitted into the meters to measure the resulting change in pressure. In the end, these units were ineffective. The flow rates were quite small and consequently produced very low pressure changes. As a result, the pressure transducers' sensitivity was not adequate and required constant calibration.

To alleviate this problem, rotometer type flow meters (Potter Meters) were used. These meters were calibrated under laboratory conditions on a flow bench to establish an accurate relationship between meter output and fluid flow rates. These meters generate a sinusoidal output voltage, the amplitude and frequency of which are proportional to the flow rate. The frequencies range from 10 to 100 Hz and the amplitudes from 0.02 to 0.20 volts rms for flow rates of 2 to 20 gallons per minute. An interface circuit was required to convert the sinusoidal output of the flow meters into the standard 0 to 10 volt d-c range required by the analog multiplexer

and digitizer. The interface circuit used consisted of a 10 to 100 gain stage followed by a peak detector and was constructed using μA741CV operational amplifiers. This circuit schematic is included in Appendix D. One of these meters is illustrated in Figure 6.21.

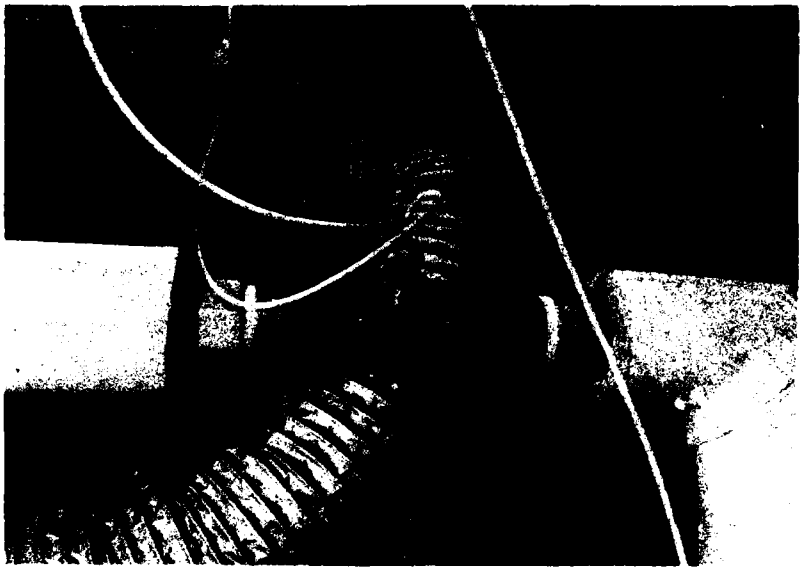


Figure 6.21 Fluid Flow Meter

6.9 Other Instrumentation

Gas meters of the type shown in Figure 6.22 were installed on the main house gas supply, the furnace supply, and the domestic hot-water tank in both the Solar Test House and the Control House. The gas meters are not interfaced with the microcomputer. Instead, periodic readings are taken by the applicable resident engineers.

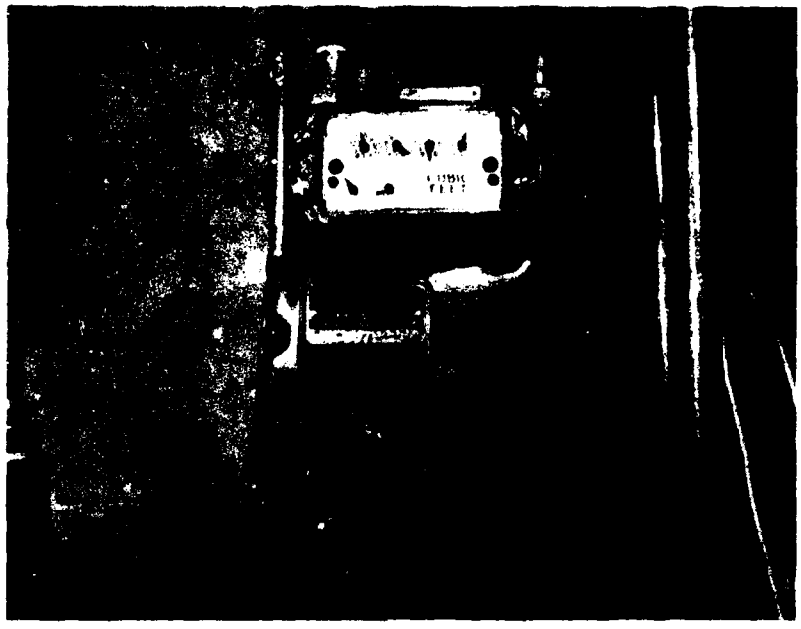


Figure 6.22 Natural Gas Meter

A comparison of the readings of the two houses confirms the performance of the solar energy system.

Electrical meters of the standard watthour type were also installed. In the Solar Test House, they were installed to monitor electrical consumption by the furnace fan, roof array pump and modulating valve, furnace heat-coil pump, ground array pump and modulating valve and the domestic hot-water preheat pump.

These meters are illustrated in Figure 6.23. In the Control House, only the furnace fan is metered as it is the only common electrical consumer in the two heating systems. Again, the electrical meters are not interfaced with the microcomputer. Instead, periodic readings are taken by the applicable resident engineers. These readings provide information for the operating cost of the solar energy system.

Finally, a manually operated float meter was installed to determine the depth of water in the thermal storage tank. It is periodically read by the resident engineer. It is illustrated in Figure 6.24.

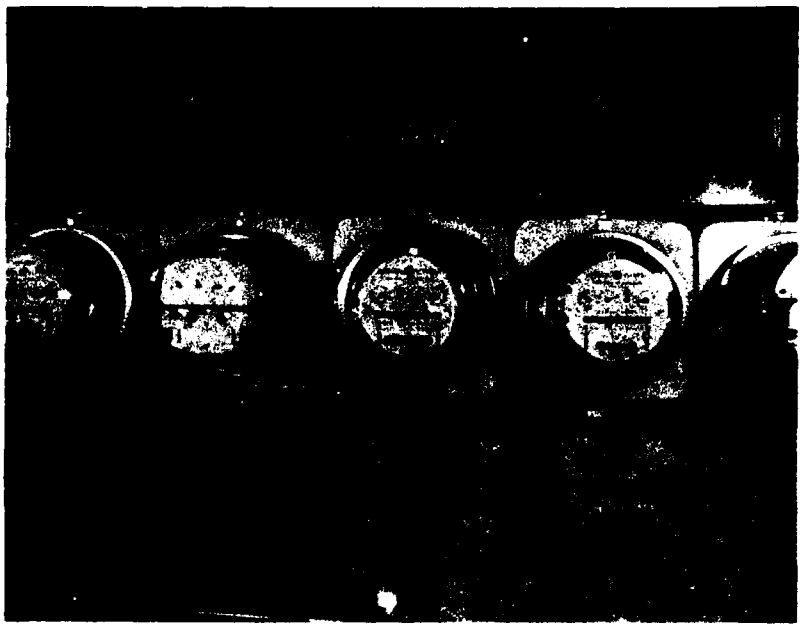


Figure 6.23 Electrical Meters in Solar Test House

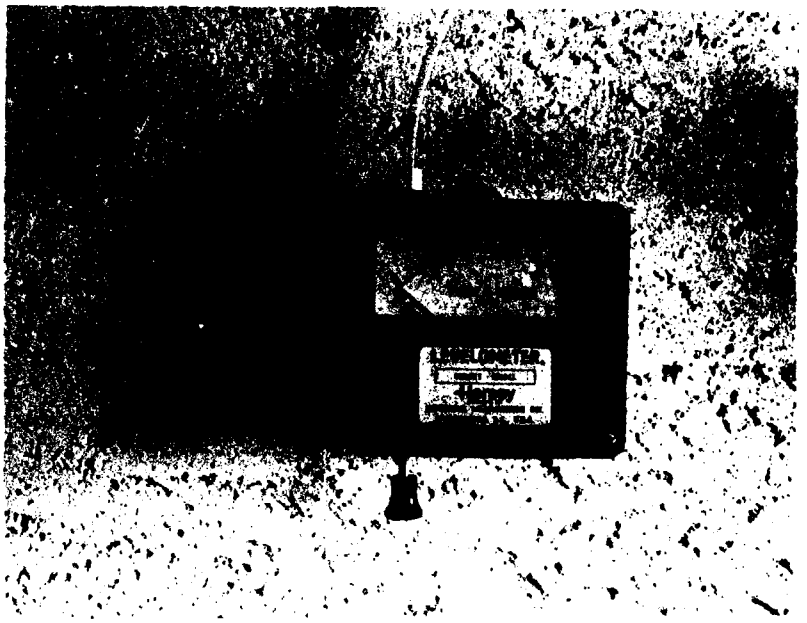


Figure 6.24 Thermal Storage Tank Depth Meter

CHAPTER 7

TEST AND EVALUATION DATA AND RESULTS

7.1 Introduction

The data required to evaluate the overall performance for a solar energy system may be grouped into the following four categories:

a. the energy that is available from the sun;

b. the portion of that energy available from the sun that is collected and stored;

c. the portion of that energy collected and stored that is delivered to the house; and

d. the total energy required by the house.

The first category is a function of the geographic location of the house and once sited cannot be controlled by technology. However, the latter three categories can be controlled by technology if they are well understood. The last category, total energy required, relates to energy conservation and becomes a static parameter once the house is built. Thus, the middle two categories, collection/storage and delivery, become the all-important system components of the solar energy heating system. Because of the dynamic nature of the energy available, these two system components must be able to function in a supporting manner with each other across a wide operating environment. The importance of this mutual relationship became quite apparent during the initial test and evaluation phase.

The actual data required to evaluate the solar energy system component performance in order to determine the effects of different control scheme configurations is significantly more detailed. The data points being recorded at the USAFA Solar Test House by the Instrumentation and Control System (ICS) are explained in Table 7.1.

The data collected is recorded on teletype roll paper and teletype computer punch paper tape. The data on the paper tape is read onto a magnetic tape for permanent storage and off-line analysis as required. The computer program used to convert the data from the paper tape to magnetic tape is included in Appendix E.

The computer program used to analyze this data is also included in Appendix E and will be referred to in detail throughout this section. In addition to the recorded data points previously shown in Table 7.1, this analysis program calculates the additional data points as shown in Table 7.2. A standard daily summary produced by this analysis program is shown in Figure 7.1. These daily summaries, together with the teletype roll paper (cut into 8-inch by $10\frac{1}{2}$-inch sheets), are filed in a daily system performance project folder.

Table 7.1 ICS Recorded Data Points at the USAFA Solar Test House

TDATA (1) = Time
(2) = Air temperature outside Ground Array
(3) = Collector surface temperature west end of Ground Array
(4) = Collector surface temperature east end of Ground Array
(5) = Water temperature out of Ground Array
(6) = Water temperature into Ground Array

(7) = Storage tank water temperature

(8) = Air temperature outside Roof Array
(9) = Collector surface temperature west end of Roof Array
(10) = Collector surface temperature east end of Roof Array
(11) = Water temperature out of Roof Array
(12) = Water temperature into Roof Array

(13) = Pyranometer output

(14) = Outer surface temperature of storage tank (inside insulation)
(15) = Ground temperature outside storage tank insulation
(16) = Hot water preheat
(17) = Hot water preheat
(18) = Actual house temperature
(19) = Desired house temperature (computer thermostat setting)
(20) = Water temperature into heat coil
(21) = Water temperature out of heat coil
(22) = Water temperature heat coil by-pass
(23) = Air temperature below heat coil

(24) Test house living area temperatures in 24-30 (31)
(25) See house as-built drawings for locations in Appendix C (32)
(26) (33)
(27) Corresponding control house living (34)
(28) Area temperatures are shown in 31-37 (35)
(29) (36)
(30) (37)

(38) = Flow rate for Ground Array
(39) = Flow rate for Roof Array
(40) = Flow rate for heat coil

(41) = Valve position Ground Array
(42) = Valve position Roof Array
(43) = Computer control output

(44) = Wind direction
(45) = Wind speed
(46) = Dew point temperature
(47) = Ambient temperature

Table 7.2 Solar Test House Data Analysis Program - Calculated Data Points

SUN

TDATA(74) = [Btu/SF = Min Available Horiz] x 10
TDATA(75) = Btu/SF = Available Horizontal (since last data point)
TDATA(85) = Btu/SF = Available Ground Array (since last data point)
TDATA(86) = Btu/SF = Available Roof Array + 144 (since last data point)
TDATA(91) = [Btu/SF = Min Available GA] x 10
TDATA(92) = [Btu/SF = Min Available RA x 10] + 144

HEAT COIL

$$TDATA(76) = \frac{\text{Btu into House}}{100}$$ (since last data point)

GAS

$$TDATA(77) = \frac{\text{Btu into House}}{100}$$ (since last data point)

TDATA(78) = (TDATA(77) + TDATA(76))/10 = Total Btu into House/1000 (since last data point)

GROUND ARRAY

TDATA(79) = Btu Collected/SF Ground Array (since last data point)
TDATA(80) = Flow Rate (GPM) Ground Array
TDATA(87) = Btu Collected/100 Ground Array (since last data point)
TDATA(93) = [Btu/SF - Min Collected GA] x 10
TDATA(96) = TDATA(93)/TDATA(91) x 100

ROOF ARRAY

TDATA(81) = Btu Collected/SF Roof Array (since last data point)
TDATA(82) = Flow Rate (GPM) Roof Array
TDATA(83) = TDATA(79) + TDATA(81) = Total Btu Collected/SF GA and RA
TDATA(88) = Btu Collected/100 Roof Array (since last data point)
TDATA(89) = Total Btu Collected/100 (since last data point)
TDATA(90) = TDATA(81) + 144
TDATA(94) = [Btu/SF - Min Collected RA x 10] + 144
TDATA(95) = TDATA(94) - 144
TDATA(97) = TDATA(95)/TDATA(98) x 100 + 100

CONTROL

TDATA(65) = 200 OFF, = 208 ON Heat Coil Pump
TDATA(66) = 224 OFF, = 232 ON Ground Array Pump
TDATA(67) = 248 OFF, = 256 ON Roof Array Pump
TDATA(68) = 208 OFF, = 216 ON Furnace Fan
TDATA(69) = 232 OFF, = 240 ON Furnace Gas

Figure 7.1 Standard Daily Summary of Analysis Program

```
!!KEY-IN
C

!!JCP

04:48 JAN 02,'03
!JOB    MAKE,PLOTS
!RUN BP,SOLARPLT
  **** SOLAR DATA PLOTTER ****
   MOUNT DATA TAPE, 200 BPI
 ENTER MIN,MAX TAPE RECORD NUMBERS
 ENTER NUMBER OF MONTH IN WHICH DATA WAS TAKEN
JULIAN DATE ?
HOW MANY PLOTS OF THIS DATA?
HOW MANY VARIABLES ON PLOT  1
ENTER THE 3 VARIABLES OF PLOT 1
HOW MANY VARIABLES ON PLOT  2
ENTER THE 6 VARIABLES OF PLOT 2
HOW MANY VARIABLES ON PLOT  3
ENTER THE 6 VARIABLES OF PLOT 3
HOW MANY VARIABLES ON PLOT  4
ENTER THE 4 VARIABLES OF PLOT 4

 HC BTU = 186170.  ( 457- 820)
 TANK WATER TEMP AT BEGIN OF RA OPERATION =  95 AT   932
 TANK WATER TEMP AT BEGIN OF GA OPERATION =  95 AT   934
 GAS BTU =  19738.  (  12 AT 1002)
 TANK WATER TEMP AT END OF GA OPERATION = 106 AT  1631
 GA BTU = 211400.  ( 417 AT 1631)
 TANK WATER TEMP AT END OF RA OPERATION = 106 AT  1635
 RA BTU = 196182.  ( 423 AT 1635)
 HC BTU = 232439.  (  95-1729)
 SUN BTU/SF HORIZ =   1461.  ( 690-1830)
 SUN BTU/SF GA =   1435.
 SUN BTU/SF RA =   1348.
 HC BTU = 240861.  (  17-1845)
 GAS BTU =  41121.  (  13 AT 2052)
 GAS BTU =  60860.  (  12 AT 2211)
 HC BTU = 243635.  (   7-2212)
 GAS BTU =  85532.  (  15 AT 2249)
 GAS BTU = 108560.  (  14 AT 2330)
              27 APR 76
*** SUMMARY OF DAY 118   (   0 TO 2345)  ***
 HOUSE BTU'S:   GAS+SOLAR= 352196.       SOLAR= 243635.  %SOLAR= 69.2
GROUND BTU'S:   AVAILABLE= 317923.  COLLECTED= 211400.  % EFF = 66.5
 ROOF  BTU'S:   AVAILABLE= 298535.  COLLECTED= 196182.  % EFF = 65.7

 PLEASE MOUNT PLOT TAPE AT 200 BPI
```

7.2 Solar Energy Available

The output from the pyranometer is used to determine the solar energy available. This output is processed by the Subroutine Sun portion of the analysis program. By examining solar radiation data available over a period of time, it appears that solar collector orientation and cloud cover are the two major factors affecting energy available to the solar collectors.

Orientation is defined by the solar collector slope (angle from the horizontal surface) and the azimuth (the projection of the normal of the solar collector surface onto the horizontal as referenced from due south). Most authorities on this subject agree that small variations in slope are more critical than small variations in azimuth. Accordingly, the best possible solar collector orientation for a particular application warrants careful consideration.

Briefly stated, the goal of orientation is to place the solar collector so that maximum solar radiation is incident upon the smallest quantity of surface area. This provides for maximum thermal gain at the lowest cost. Because it is not cost effective to install flat plate collectors so as to follow the sun and have their surfaces remain normal to the beam radiation, it is necessary to determine the period of time over which energy gain is to be maximized. Energy gain maximized over a full year would define an orientation different than that maximized over a two-month peak of a heating season. The application must also be considered. Space heating would require a significantly different orientation than air conditioning. By determining the sun position (azimuth and altitude) for the particular time period of

interest in conjunction with the energy required from the solar collectors, an optimum collector orientation can be determined.

In addition, the type of clouds, the time of day when they appear, and their duration are major factors that affect solar collector performance and thus impact their orientation with respect to azimuth. A good example of such impact is the daily occurring afternoon thunderstorms at the Air Force Academy during the summer months. This factor suggests that for maximum energy gain in the summer, the morning sun should be favored thus defining a requirement for a south-southeastern solar collector azimuth. Although weather factors cannot be controlled, they certainly need to be evaluated to both estimate the amount of energy available as well as the proper solar collector orientation to maximize solar energy collection. Careful consultation with weather personnel is an absolute requirement. General weather trends over the past five to ten years for a location will provide the information on cloud cover described above. The effect of solar collector orientation on the amount of solar energy collected and stored at the USAFA Solar Test House will be discussed in detail in the next section.

There are several methods for determining the solar radiation available at a particular location. The best method is direct measurement. This method is time consuming and costly. If this method is not feasible, empirical calculation techniques or generalized charts with isoheliodynamic contours may be used. The accuracy of these methods depends on the experience of the user. Moreover, in the case of the latter, the localized effects of air pollution may not be considered.

A computer program to calculate the amount of solar radiation available on a surface was recently developed at the Air Force Academy. A listing of this program is included in Appendix E. This program has proven to be acceptably accurate for design purposes considering clear day radiation only, but requires some judgment in handling the effects of cloud cover.

In summary, the best possible information available on solar radiation should be used in any design process. Any inaccuracies in this determination can be projected directly to overall solar energy system performance estimates.

Appendix F contains the tabularized data summaries for the USAFA Solar Test House from December 1975 to May 1976. As can be seen, the average monthly solar insolation has ranged from a low of 675 Btu/SF/Day to a high of 1575 Btu/SF/Day, values that are significantly higher than the national average. In addition, typical computer plots of selected variables versus time for random days are included in Appendix G. Daily Solar Curves are among those included.

7.3 Solar Energy Collected and Stored

The amount of solar energy collected and stored is calculated by using the following equation:

$$Q_{collected} = (\dot{m})(C_p)(\Delta T)(C)$$

where

$\dot{m}$ = mass flow rate (variable)

C_p = specific heat of collection fluid

ΔT = temperature drop across the heat exchangers in the storage tank (variable)

C = control function (1 or 0, On or Off)

All calculations for energy collection and storage are performed in the ground array and roof array subroutines of the analysis program.

One of the main thrusts of this project has been to identify the major solar energy system variables, other than weather patterns, that affect system performance. Work accomplished to date has provided significant information on these system variables. The system variables that appear to impact collection and storage of solar energy most significantly are summarized as follows:

Ground and Roof Array Variables

a. slope and azimuth
b. working fluid
c. surface area
d. plumbing configuration
e. collector construction
f. control algorithm
g. cost

Thermal Storage Tank Variables

a. storage mass and volume
b. insulation
c. location
d. control algorithm
e. cost

Cost is considered to be a significant variable under each heading and is certainly related to each other variable, but is listed separately to stress its significance. The final test for evaluating overall system performance is to determine cost per unit of energy delivered. This will be discussed in Chapter 8.

Solar collector azimuth is not a variable in this project. Both arrays face due south. The slope of the roof array is fixed at 52° and the slope of the ground array is a variable which was operated at 45° during this past winter. As a result, significant variance in energy received was observed. This information is presented in detail in Appendices F and G and summarized in Table 7.3 and Figure 7.2.

Table 7.3 Average Monthly Solar Radiation Values (Btu/SF/Day)

Month	Horizontal	Ground Array (45°)	Roof Array (52°)
December (1975)	675	1249	1348
January (1976)	674	1427	1464
February (1976)	985	1684	1708
March (1976)	1236	1666	1645
April (1976)	1445	1500	1419
May (1976	1575	1295	1195

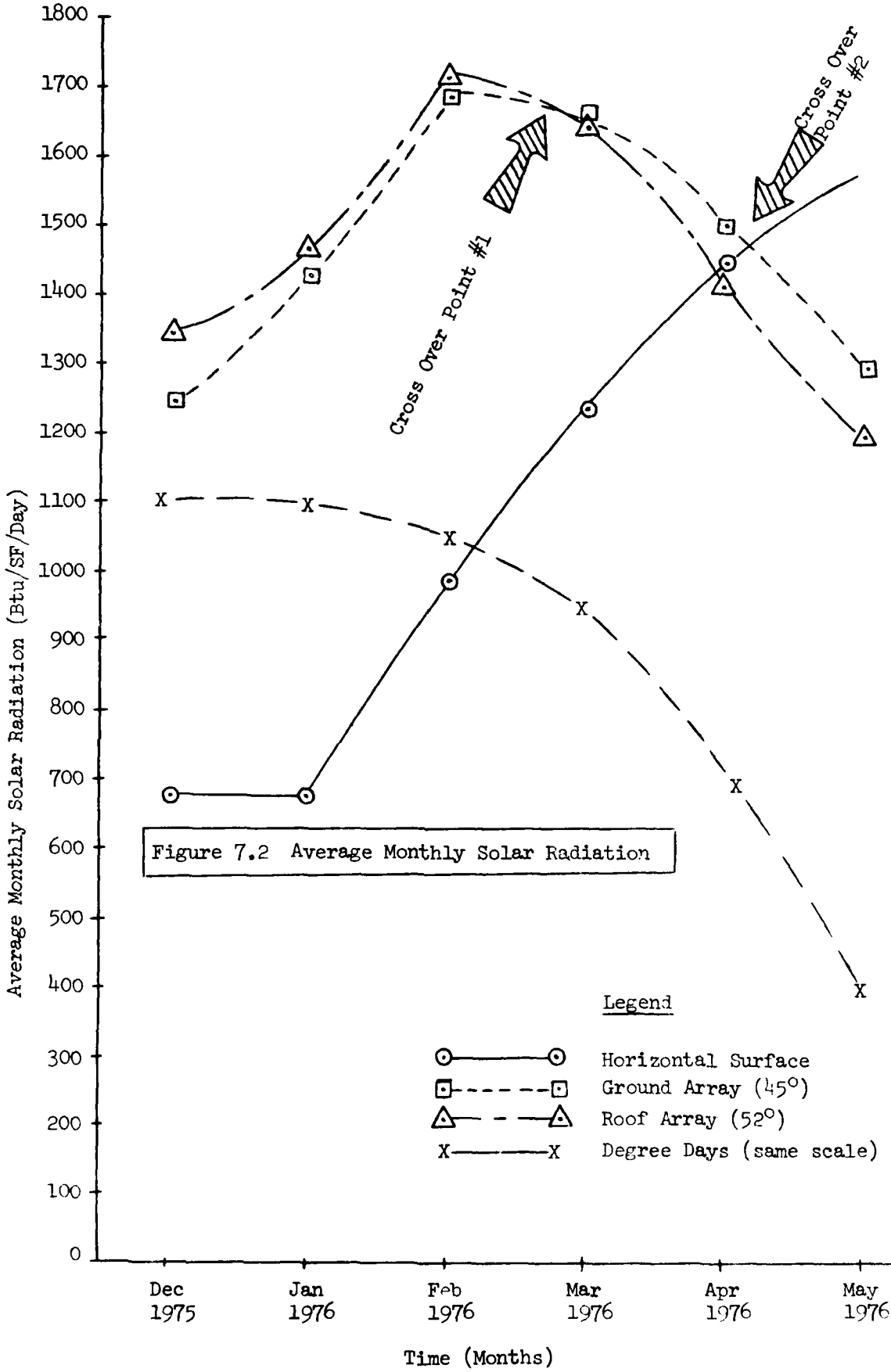


Figure 7.2 Average Monthly Solar Radiation

As can be seen, during the period of greatest heating demand (period of maximum number of degree days), the arrays received much more solar energy than the horizontal surface because of the slope. In comparing one array to the other, the roof array outperformed the ground array because it was more normal to the sun altitude. This changed in March due to the increase in sun altitude as is reflected in Figure 7.3 and Table 7.4 below.

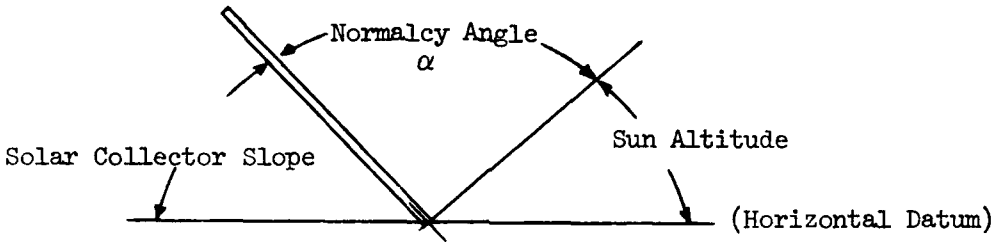


Figure 7.3 Slope-Sun Altitude Relationship

Table 7.4 Slope-Sun Altitude Relationship

Month*	Sun Altitude	α for Ground Array (45°)	α for Roof Array (52°)
Dec	27°	108°	101°
Jan	30°	105°	98°
Feb	40°	95°	88°
Mar	50°	85°	78°
Apr	62°	73°	66°
May	70°	65°	58°
June	74°	61°	54°

* All sun altitudes for 21st of month at 1200 hours)

In reviewing the information presented in Figure 7.3 and Table 7.4, the slope configuration that provides an α angle closest to 90° will receive the most solar energy. This explains Cross Over Point #1 on

Figure 7.2. The ground array α of 85° is closer to 90° than the roof array α of 78°. The second significant observation is Cross Over Point #2 in Figure 7.2. Here, the horizontal surface begins to receive more energy than the inclined surfaces. The explanation for this, as shown in Table 7.4, is that the α angle for May for both arrays becomes less than the sun altitude. This is not critical for a space heating system because the corresponding heating demand is substantially less as shown by the Degree Day Curve.

In summary, these observations reinforce the need to consider the major application of the solar energy system in selecting its proper orientation. For the USAFA Solar Test House, the slope was determined from the general algorithm, latitude plus 12°, which rounded up to 52°. This algorithm is based on satisfying heating demand for the critical mid-winter time period which happened to be the situation at the Air Force Academy. Perhaps the best approach is to review the degree day demand to be satisfied against the sun altitude as shown in Figure 7.4, identify the critical periods and attempt to then select the proper slope on the basis of what is available. It is anticipated that next year, the ground array at the USAFA Solar Test House will be changed to 60° to further investigate the effects of collector slope.

The collection fluid used to date has been a 50 percent by volume mixture of water and ethylene glycol. This mixture will vaporize at the ambient pressure in the hydraulic lines above 200°F, and since the array temperatures can occasionally exceed 200°F, some vapor locking has been experienced. This problem has been partially alleviated by proper charging of the arrays. A minor plumbing modification, which

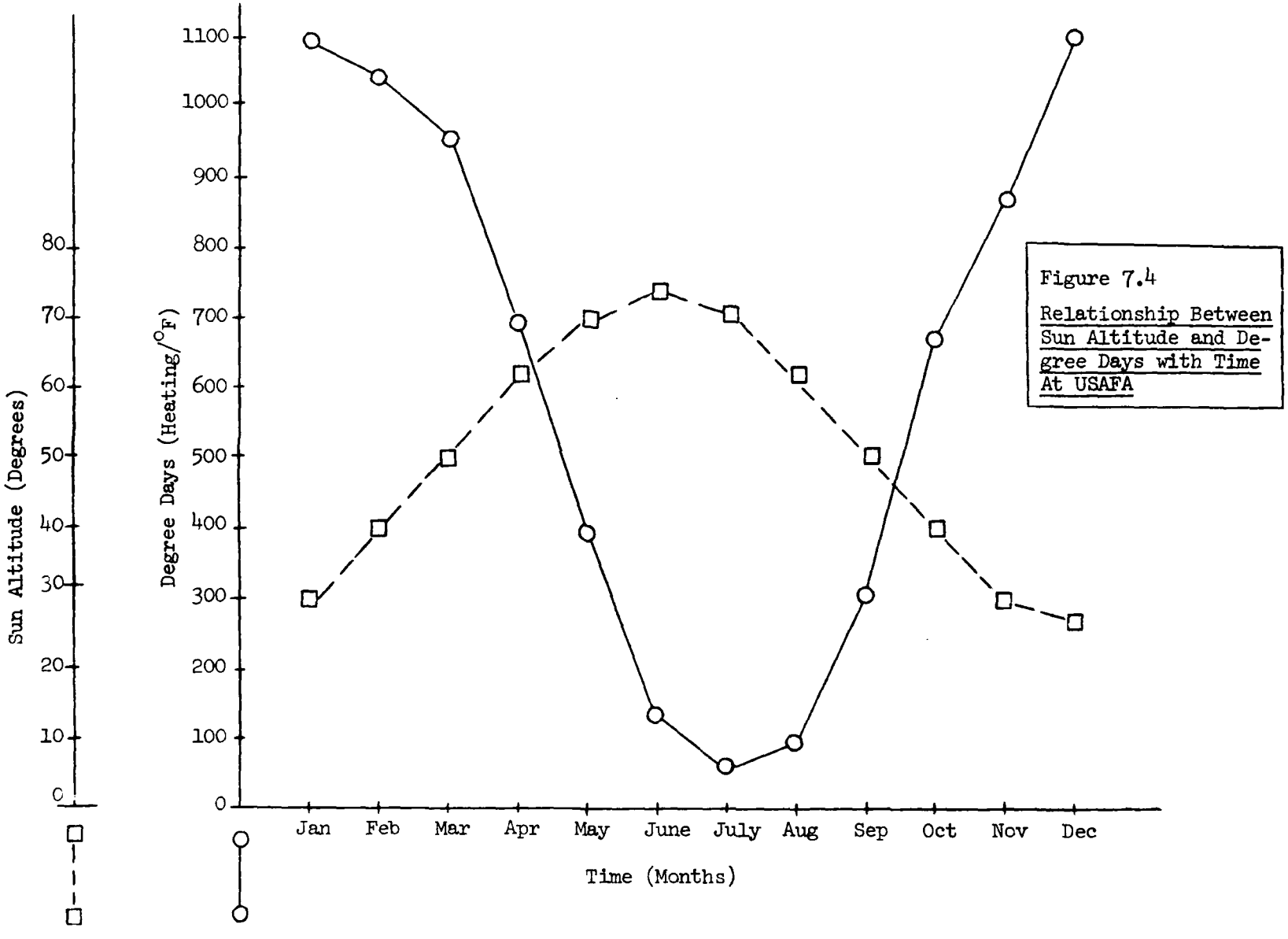


Figure 7.4

Relationship Between Sun Altitude and Degree Days with Time At USAFA

will be described in Chapter 9, will make a significant contribution towards its elimination.

Two other working fluids for heat transfer are available and have been used in various projects. These two fluids are Dowtherm J and Therminol 60. A list of their comparative characteristics with that of ethylene glycol are reported in Table 7.5. Because of the toxicity and odor associated with Dowtherm J and the causticness of Therminol 60, it was determined that their use in a residential dwelling incorporating a domestic hot water preheat system should not be pursued at this time. Although either of the alternative fluids would require less mechanical energy for pumping, less heat would be actually collected and stored due to the lower specific heat. Unlike ethylene glycol, these alternative fluids cannot be mixed with water. The 50 percent mixture of water and ethylene glycol has the advantage of a high specific heat (C_p = 0.77).

Solar collector surface area can be used as the major adjustment factor for system output once energy available and energy required have been determined. It is possible to cover uncertainties in design by buying more solar collector areas than needed, but then cost per unit of energy delivered increases. The main consideration is to insure that the entire collector area installed is effectively used. Manufacturers solar collector performance specifications in terms of the number of Btu's gained per square foot are based on certain required conditions of which there appears to be no industry standard established to date. It must be determined if these conditions will exist for the

Table 7.5 Comparison of Working Fluids for Heat Transfer

PROPERTY	DOWTHERM J	THERMINOL 60	ETHYLENE GLYCOL
COMPOSITION	Isomers of Alkylated Aromatics	Polyaromatic Compounds	Hydrocarbons
COLOR	Clear	Light Yellow	Clear
FREEZING POINT	-100°F	-90°F	Function of Pressure
BOILING POINT	358°F	--	198°F
FLASH POINT	145°F	310°	UK
FIRE POINT	155°F	320°	UK
AUTO IGNITION TEMPERATURE	806°F	835°	UK
AVERAGE MOLECULAR WEIGHT	134	250	62
VISCOSITY AT 100°F	0.7	0.59	16.2
DENSITY IN LBS/GAL	7.25 at 60°F	8.33 at 75°F	9.25 at 72°F
SPECIFIC HEAT BTU/LB/°F	0.470 at 150°F	0.420 at 150°F	0.366 at 72°F
CAUSTIC	Yes	Yes	No
VAPORS TOXIC	Yes	No	No
BIODEGRADABLE	Yes	UK	Yes
ODOR	Strong	Faint	Very Faint
COST	$4.00/Gal	$4.00/Gal	$3.00/Gal
AVAILABLE	From Manufacturer	From Manufacturer	From Chemical Suppliers
CORROSIVE	No	No	No (with additive)

field application being considered before the required collector area and syster performance can be predicted. The plumbing configuration and control algorithm used will have much bearing on this.

An accurate hydraulic analysis of the array plumbing configuration is required. The current plumbing configuration as shown in the as-built drawings in Appendix C does not insure even flow conditions. Pressure buildup in any one of the four loops in each array can cause flow through that loop to decrease and hence increase through the other loops. This reduces collector area for a given flow rate and environmental conditions and hence can seriously reduce energy collection. Careful adjustment of the balancing cocks has alleviated this problem to a great degree.

Solar collector construction in terms of the number of glass covers, absorbing surface, working fluid conduit configuration, and insulation must be adequate to provide the required system temperatures when operating in the design environment. The minimum system operating temperature should be capable of providing useful energy to the system at all times.

The control algorithm of the solar arrays may be the most significant variable. It is based on three temperature sensors, a constant speed centrifugal pump, two heat exchangers and a modulating flow control valve as schematically shown in Figure 7.5.

To begin operation, the solar collector surface temperature is compared to the storage tank temperature. If the surface is warmer by $20^{\circ}F$, the array pump is turned on. This 20° ΔT appears to be sufficient to prevent any excessive cycling of the system as it

begins operation and also with this ΔT, energy will not normally be pumped from the storage tank during operation.

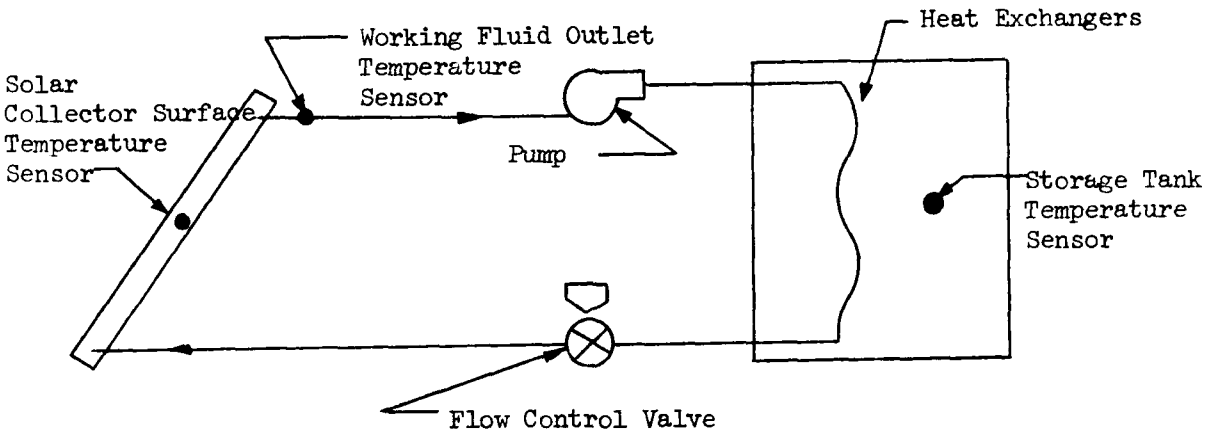


Figure 7.5 Collection and Storage Control Algorithm Supporting Mechanical Components

After the 20° ΔT is established, the collector pump is started and the flow control valve is placed at mid-position (flow = 8 gpm). Then, the temperature of fluid leaving the solar collector is compared to the storage tank water temperature. Based on this ΔT, the fluid rate is adjusted to always maintain the collection fluid warmer than the tank fluid temperature. In other words, the system adjusts itself automatically to the energy level as indicated by temperature present in the system at any point in time. If the system is operating and the ΔT between the working fluid leaving the solar collector and the storage tank is less than 3°F, the flow control valve will be closed one step from its present position. This will occur every eight seconds (one step is 1/255 of the valve stem travel).

If the ΔT has not been improved by this lesser flow rate when the valve reaches 64/255 (flow = 2 gpm) open, the system will be

shut down and will wait to recycle based on the original 20° ΔT. If the working fluid tank temperature ΔT is between $4^{\circ}F$ and $9^{\circ}F$, the valve will remain in its present position. If the ΔT is $10^{\circ}F$ or greater, the valve will be opened every eight seconds. Examination of the data summaries in Appendices F and G for this section will show how flow rate adjusts automatically to the energy available.

The key to this control concept is that the entire operation is based on a temperature difference and not an absolute temperature. This allows the system to react appropriately to any given energy level. It appears that this control method will always insure that if the system is operating, it will be adding energy to the storage tank.

The ΔT's, flow rates, and sensing rates are all control algorithm variables. Several points about these variables with respect to impact on system performance have already become evident and have provided guidance for future work. Of these, the impact of the variable flow rate has been most noticeable.

A variable flow rate definitely allows for extended periods of operation. The data shows many periods of operation when the flow rate had to be reduced to be able to gain energy. The system may not operate at maximum efficiency during these periods of reduced flow conditions, but it will still gain useful energy. Starting the pumping operation at a reduced flow rate has also helped to prevent system cycling. It is possible to wait until the ΔT between the collector surface and the storage tank is larger and then pump at full capacity, but the object has been to maximize energy gain. Regardless of how it is accomplished, operation should always begin as soon as the collector

surfaces are sufficiently warmer than the storage medium to gain more energy than is being expended to operate the system.

The relationship between the storage volume and the remainder of the system is extremely important. If the storage volume to collector area ratio is large (say, greater than 2 gal/SF), the storage mechanism will react very slowly. This can improve collector performance as the collector fluid inlet temperature will remain lower. However, the risk in doing this is that the temperature of the water in the storage tank may not be high enough to be used for its intended purpose.

The storage system presently consists of approximately 2000 gallons of water and 14,000 pounds of concrete. This is equivalent to a storage mass of 2336 gallons of water. The gross solar collector area is 546 square feet, for a ratio of 4.3 gallons per square foot of solar collector (or 36 lbs/SF). The data to date has demonstrated that this ratio of storage mass/collector area is much too large for this particular application. Although the collection efficiencies are very high, overall system performance is not appropriately high.

In reviewing the performance data presented in Appendices F and G, the collection and storage phase of the solar energy system has averaged a 44 percent efficiency for the period December 1975 through April 1976. However, for this same time period, the heating cycle phase was only able to utilize 28 percent of this for space heating and thus satisfy only 21 percent of the house heating demand. These figures are perhaps conservative because of the start-up problems encountered in December and January. Nevertheless, it does point out a problem between two system components.

It is not unusual for the collection and storage phase to, on a daily basis, collect between 300,000 to 400,000 Btu's of energy, raising the temperature of the water in the storage tank from 90°F to 104°F. However, none of this energy is usable as 105°F is presently the lowest temperature acceptable in the storage tank to be used for house heating. With 105°F water in the storage tank, air for heating the house will be provided at a temperature of approximately 98°F at the heat coil and approximately 85° to 90°F at the registers at the end of the distribution system into the house. At the present air circulation rates, it was decided that any cooler air would not be acceptable as air less than body temperature blowing on the body would have the effect of cooling the body while, in fact, warming its environment. By replacing the registers in the duct work with diffusers, this activation temperature can be lowered significantly. However, more study is required before this lower limit is defined.

Conversely, if the storage volume is smaller, the storage will react more rapidly with a corresponding decrease in collection efficiency as the storage heats up. What has to be determined is what temperatures are required in the storage tank and then size it appropriately to obtain these temperatures during normal operation. By decreasing the size of the present storage tank by approximately one-third, the collection efficiency may decrease slightly but the overall system performance will improve or the storage will be usable more of the time. The modifications planned for this storage volume to improve overall system performance will be discussed in more detail in Chapter 9.

Appropriate storage insulation can be determined based on the expected operating temperature of the storage tank and the temperature surrounding the storage tank. The placement of the storage tank will also affect the amount of insulation required to prevent excessive energy losses. Energy losses from the storage tank should be examined extremely closely as they can significantly affect overall system performance. These losses should be kept to the most economical minimum.

7.4 House Heating Demand

As stated in Chapter 6, the furnace gas consumption is metered and periodically manually read and recorded. The gas flow rate into the furnace is a constant and has been determined to be 2.069 cubic feet per minute (cfm). This flow rate is used by the subroutine gas portion of the analysis program to determine the total gas used and Btu's provided.

The solar Btu's delivered to the house are calculated by the subroutine heat coil portion of the analysis program. The heat coil loop has a constant flow rate and the water temperature into and out of the heat exchanger (coil) installed in the supply air side of the furnace plenum is constantly measured.

No effort has been made to determine the efficiency of the gas furnace. For this report, efficiencies of 100 percent and 70 percent are used. The percent of solar heating is based on the solar Btu's supplied divided by the total (solar and gas) Btu's consumed by

the furnace. It is entirely possible that the furnace is much less efficient in a gas heating mode than in a solar heating mode. This would be due primarily to the flue losses in the gas heating mode. A determination of furnace efficiency will be made before the next heating season.

The most significant variables in house heating demand, other than weather, are:

a. general house construction;

b. placement and sensitivity of the house thermostat;

c. the desires and conduct of the residents.

Significant information on measures to reduce house heating demand by providing more insulation, weather stripping, storm windows, etc., is readily available. Accurate analysis of just how cost effective these measures are for existing construction is somewhat less available. During the next heating season, an extensive study will be performed on the Solar Test House to evaluate various energy conservation measures. With the instrumentation already available in the house to evaluate the effects of any modifications, it should be possible to accurately report the results. There is no doubt that in many Air Force facilities, cost effective energy conservation measures are possible and should be investigated.

The upstairs living area in both the Test and Control House is instrumented with temperature sensors as shown in the as-built drawings in Appendix G. These sensors are arranged in a diagonal pattern across the house from the southwest to the northeast corner. Data from these

sensors indicate as much as 15°F difference between corners of the house during the daytime with this difference decreasing toward the evenings. In the evenings, the northeast corner of the house was generally 5°F cooler than the rest of the house. The gas range in the kitchen raised the temperature of this area during operation by 5 to 10°F.

Solar gain and internal generation must be considered when placing the thermostats used to control the house heating system. Excessive influence by either external or internal effects must be limited as much as possible. Careful consideration should be given to what portion of the house must be at what temperature during a certain time period. It should be determined if these are portions of the house where temperature fluctuations can exist without detracting from house comfort. A thermostat carefully placed to react to only the necessary requirements can both increase living comfort and save energy.

The sensitivity of the thermostat is also important. The operating limits for the thermostat should not allow noticeable cooling or overheating of the facility. The Solar Test House is presently being controlled with a 2°F dead band. If the temperature is more than 1°F below or above the desired temperature setting, the system will start up or shut off.

As can be seen from the computer plots in Appendix G, the gas furnace provides energy to the house at a much faster rate than the solar heating system. A sensitive thermostat is definitely required to prevent the furnace from overshooting the actual heating requirement.

Thermostat placement and sensitivity are minimal cost considerations but can definitely provide beneficial energy conservation results when given proper attention.

Significant information on the impact of various measures taken by the resident also exists. It appears that the best possible course of action in this regard is to insure that all military housing occupants are aware of the magnitude of the savings possible by actively employing energy conservation means. High thermostat settings, leaving doors and windows open and leaving unnecessary lights on are examples of energy consumption that can be reduced by awareness.

For the period of time observed, the Control House consumed approximately 4000 cubic feet of natural gas per month for domestic hot water heating, while the Solar Test House consumed approximately 2500 cubic feet. Accordingly, it would appear that the pre-heat system provided 38 percent of the domestic hot water demand at a savings of 1500 cubic feet of natural gas.

7.5 Domestic Hot Water Heating Demand

The gas consumed by the hot water heaters in both the Test and Control Houses is metered. The temperatures of the water into and out of the hot water pre-heat coil are continuously recorded by the ICS. However, the operation of the hot water pre-heat system is not controlled by the ICS. This system is an add-on portion of the project and its operation is controlled by a thermostat, a timer and flow switch as described in Chapter 6. It is anticipated that this system will be interfaced with the ICS at a later date for detailed study. The energy supplied by the solar system for water heating is determined by comparing the water heater gas consumption of the Test and Control Houses.

The only significant variable in hot water demand appears to be the family size and habits of the house residents. The demand appears to be fairly steady during the year.

One design variable that can impact pre-heat cost and operation is the placement of the pre-heat coil. As can be seen from the as-built drawings in Appendix C, the pre-heat coil is located external to the storage tank. This necessitates control, piping and a pump to move the water from the storage tank to the coil. Depending on the magnitude of the demand and its impact on the performance of the storage tank, it may be less expensive to simply route the domestic supply to the water heater through a heat exchanger immersed in the storage tank. This would eliminate the need for control and a pump for this loop and also possibly reduce the plumbing expense depending on the position of the storage and water heaters.

7.6 System Modeling Techniques and Results

There are few simulation programs available today. TRNSYS, a transient simulation program, prepared by the Solar Energy Laboratory at the University of Wisconsin-Madison, is one operational solar system simulation/analysis program. The Civil Engineering Research Laboratory (CERL) is presently developing another solar system simulation program for the Air Force Civil Engineering Center (AFCEC). However, no results of this effort have been available to date.

A study of TRNSYS was begun this spring to determine its applicability to the Solar Test House. It does not appear to be readily possible to simulate a variable flow rate through the collectors with this program. From analysis of system performance to date, it appears necessary to have this capability. The evaluation of TRNSYS will be continued this summer and next fall to allow detailed analysis of its full capabilities. The CERL program will be examined as soon as it is available.

The computer program to calculate solar radiation availability discussed earlier and the analysis program should provide a basis for further development of existing simulation programs or possibly new simulation programs as required. Heating and cooling load programs are readily available from various commercial sources and can be used in simulation efforts.

One of the major problems with all these programs is how they compare with observed data. In addition, most of these programs are very long and complex and require experienced people and a great deal of computer time to produce a product. The data base that exists as a

result of this project is an excellent place to start answering these questions and determining the usefulness of many of these computer tools. This data base has sufficient detail and completeness to evaluate both component simulation programs and system simulation programs.

It should be possible with the results of this project to develop a design tool capable of accurate system simulation and also capable of the flexibility required to be applicable to other systems. This design tool would probably also be lengthy and require extensive computer time and facilities. However, it could be employed at a central point to evaluate various proposed systems. The main objective should be to develop an accurate system simulation program and a central point for its application. This will allow the analysis of both in-house Air Force efforts or any contracted services the Air Force may require.

CHAPTER 8

CONCLUSIONS AND RECOMMENDATIONS

8.1 General

On the basis of the experience gained with this project to date, a number of general conclusions may be drawn, as follows.

a. It appears that all necessary solar energy system hardware components are commercially available today. The industry is new and growing and is presently without agreed upon standards. Accordingly, some care must be used in selecting the proper components for the application being considered. Nevertheless, the components are commercially available and significant work is being done to improve them. Probably the only exception to this is the necessary control systems. Although control system components are available, there is some question as to whether or not they are truly cost effective and provide for the full thermodynamic use of solar energy. Because of the large capital cost associated with solar energy systems, additional work in control systems would be very beneficial.

b. In a competitive economic environment with conventional fossil fuels, solar energy presently falls somewhat short, especially in the case of single applications to single family residential dwellings. The combination of high capital costs and low conventional fossil fuel costs accounts for this observation. Recognizing the future of the availability of energy in the United States, however, the relationship between solar energy and conventional fossil fuels could suddenly

change. As a national energy policy comes closer to being developed, this relationship will become clearer. In the meantime, any efforts at reducing the solar energy system capital costs would be very productive, either by reducing the cost of the solar collectors or by adopting sound facilities energy conservation measures. At this time, multi-unit, large-scale applications in some parts of the United States, especially of the new construction category, can probably be shown to be cost effective. Perhaps a cluster concept with one solar collector bank serving a number of single family dwellings would also have merit at this time.

c. Although solar energy systems are not completely cost effective in the private sector at this time, it may be that they offer distinct and immediate military applications. As an example, the ground array used in this project could easily be used at remote sites for space heating and in contingency theater areas as a part of the United States Air Force's "Bare Base" Program. This ground array is capable of being modularly prefabricated, can be relocated and can be made air transportable. In addition, with its adjustable slope feature, it can be configured for any solar energy application involving heating and/or cooling at any latitude for any time period.

d. General contractors will not be intimidated by constructing solar energy systems in the future. Today, the more than 600 solar homes in the United States are receiving favorable media exposure. In addition, many educational institutions are offering short courses at the layman's level in solar energy technology. Thus, it can be expected that acceptable construction contracts can be obtained with competitive

bidding through an Invitation for Bids rather than through the more expensive Request for Proposal procurement mechanism.

8.2 Specific Project Conclusions

The following specific conclusions may also be drawn on the basis of the experience gained with this project to date.

a. Orientation of the solar arrays to include both slope and azimuth must reflect the period of time over which the energy gain required is to be optimized.

b. Solar array plumbing providing for the flow of the heat transfer working fluid must be such that the entire solar collector surface can be used continually.

c. Variable flow rate schemes, as opposed to fixed, provide for extended solar energy system operation and thus contribute to maximum thermal gain.

d. Roof arrays should be constructed on the leading edge of the roof to allow the snow to fall clear of the roof rather than accumulating. This subsequent accumulation could cause serious structural loadings on the roof and could prevent the solar collectors from working properly.

e. Ground and roof arrays, other than for different slopes, were essentially identical in performance.

f. Maintenance on the ground array was easier to perform than on the roof array.

g. No solar collector damage attributable to either adverse weather or vandalism was observed on either the ground or roof arrays.

h. Working fluid of a mixture of water and ethylene-glycol

should continue to be pursued for heating applications in any climate where freezing is a problem.

i. Solar collectors must be covered during installation and non-operational daylight periods to protect them from thermal damage.

j. Solar collectors used have shown no serious deterioration to date. A small amount of outgassing and some very negligible surface coating bubbling has been observed.

k. Concrete tanks are viable thermal storage tanks. They should be coated with a waterproofing agent, insulated and amply reinforced throughout especially at the corners and other discontinuities.

l. Storage tank size, with respect to the rest of the solar energy system, has the most significant impact on both the system heating efficiency as well as on the system collection efficiency. The storage volume must provide compatibility between both system components. If not, seriously imbalanced component operating efficiencies will result.

m. Control systems should be based on temperature differentials rather than a particular preset temperature for the collection cycle. The preset temperature for the heating cycle should be as low as practicable to produce a comfortable living environment.

n. Control systems must be capable of adjusting themselves automatically to any environmental condition in real time. Activity related to this project indicates that a control system similar to that used in this project, capable of this requirement and others, can be cost-effectively produced with existing solid state electronic technology.

o. Based on the promising results of this project to date, the Air Force should continue to pursue field scale, real property oriented solar energy applications.

9.3 Specific Recommendations for Continuing Project Work

The Solar Test House has performed well to date and has provided a significant amount of valuable information and operational experience. The instrumentation installed has provided a detailed view of the overall system performance and has allowed the various system components to be closely scrutinized. However, although the solar energy system has performed well to date, it can be expected to do even better. Specifically, based on observations and study of the data gathered to date, the following areas are believed to need additional work and investigation.

a. Some system modifications are required to further improve its overall performance.

b. Some operational variations of system components are required to further evaluate their impact on overall system performance.

c. Some additional instrumentation is required in order to support an even more detailed evaluation of component performance.

In response to the above three general areas of additional work and investigation so recommended, the following specific work items are recommended for accomplishment.

a. Install an additional heat exchanger in the thermal storage tank on the ground array loop only. This work is necessary to determine if a greater temperature differential can be extracted from the working fluid and thus improve heat transfer. The roof array loop should remain unchanged in order that it may serve as a performance reference. The existing parallel plumbing configuration should be retained.

b. Lower all heat exchangers in the thermal storage tank to within one inch of the bottom. This work is necessary to both provide for better heat transfer and to allow for the tank volume to be varied during the year; i.e., lower volume in the winter and a greater volume in the summer. In this regard, a storage tank volume of 1500 gallons is recommended for the critical months of December and January.

c. Install an air bleed line along the top of the solar collectors on the ground array terminating in an expansion tank mounted on the back of the array. This work is necessary to determine if the random problem of vapor locking can be more positively dealt with.

d. Install pressure gauges on the supply and return lines from each solar collector series on the ground array. This work is necessary to further evaluate flow patterns.

e. Install temperature sensors in the six remaining solar collector panels on the ground array presently without sensors. This work is necessary to also further evaluate flow patterns.

f. Install a multiplexer and other necessary electronic components to include a-c electric power to the ground array. This work is necessary to interface the additional temperature sensors on the ground array to the microcomputer.

g. Vary the slope of the ground array during the next heating season, especially during the months of December and January. This work is necessary to further evaluate the effects of solar collector orientation on system performance.

h. Vary the activation temperature of the solar energy heating cycle of the system control algorithm downward. This work is necessary in order to identify the lowest temperature at which the solar energy system can heat the house without discomforting the occupants and thus extract maximum useful thermal energy from the system. In this regard, it is recommended that a 95°F activation temperature be used rather than the present 105°F activation temperature.

i. In support of the preceeding, investigate the use of diffusers as replacements for the existing registers in the present heating ducts. This work is necessary to minimize the effects of delivering lower quality heat to the house by preventing it from being directly blown onto the occupants.

j. Recalibrate all the system sensors, gauges and flow meters prior to the next heating season to insure data accuracy.

k. Make the Solar Test House (and its referenced Control House) more energy conservative. As has been pointed out in this report, the cost effectiveness of solar energy systems can be enhanced if such systems are done in concert with energy conservation activities, particularly in the case of retrofit schemes. By initiating energy conservation steps, the total energy demand of the house can be substantially reduced. This action will have the corollary effect of reducing the amount of solar collectors required. Because the solar collectors represent approximately half the capital cost of a solar energy system, energy conservation steps can have a significant effect on the cost effectiveness of a solar energy system. Recognizing this to be the case at the Solar Test House, work has been accomplished to

identify areas of high energy loss. Working with an AGA infrared camera with a CRT display (cathode ray tube) with both a photographic and video tape record at the Solar Test House, a number of areas of high energy loss were identified. This thermograph analysis showed the following:

(1) extensive air infiltration at the interface of exterior walls and ceilings;

(2) extensive air infiltration around exterior entrance doors;

(3) marginal insulation in the exterior walls; accordingly, reinsulating the exterior walls and the outer perimeters of the ceilings with foam insulation and vestibuling the exterior doors should be investigated.

1. Develop and/or modify the existing computer programs to aid in the design and analysis of future Air Force solar energy projects.

The effects and results of specific work items recommended for accomplishment here should be reported in the next annual project technical report in June 1977.

(NOTE: The thermography study referenced in this section is a part of the Air Force Academy's Energy Conservation Program. This program includes a number of measures to conserve energy consumption in family housing which include insulating the crawl spaces, insulating the window highlight panels, installing restricted flow showerheads, and installing automatic setback thermostats. The thermography study will be dealt with in detail in a later report.)

8.4 Project Related Cadet Education Program

This project is the major part of the Air Force Academy Solar Energy Program. Associated with this program is the education of cadets, the interaction of which, on the basis of technology transfer, was a part of the original justification for this project. The project has been extremely valuable to cadet education. For many, it has provided the most valuable form of education available - that of "hands on experience." For the past year, two courses in solar energy have been offered. The Solar Test House and its performance data are used to directly support these courses.

The first course, entitled Solar Energy Applications, is the basic course. It deals with the following four topics:

a. what is solar energy, what is available and how much can be used;

b. what are the heating and cooling energy demands for conventional real property facilities;

c. what systems are required to interface the preceding two topics with each other;

d. what refinements can be made to make the interface more efficient in a technical sense and more cost effective?

The cadets that successfully complete this course may go on to the second course which is an independent study course, Solar Energy System Test and Evaluation. Some of the topics pursued this year included: (1) thermal effects on concrete storage tanks; (2) Solar Test House data reduction and evaluation; (3) infrared heat loss analysis; and (4) evaluation of the Solar Test House arrays plumbing configuration.

Fifty cadets completed the former course and eleven completed both courses this past year. These latter eleven cadets plus an additional 29 who completed only the first course, recently graduated and are now active duty Air Force officers. Because of the success of these courses, they will be offered on a continuing basis for the foreseeable future.

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APPENDIX A

DEGREE DAYS AT THE UNITED STATES AIR FORCE ACADEMY

Appendix A: DEGREE DAYS AT THE UNITED STATES AIR FORCE ACADEMY

Year	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
1963	1236	789	823	497	212	75	0	44	83	303	697	1050
1964	1177	1179	1027	616	260	144	14	122	204	615	834	1069
1965	1066	1004	1305	632	255	173	55	145	440	566	781	982
1966	1228	1104	846	755	391	154	21	161	278	648	811	1168
1967	1042	1795	783	698	533	267	82	173	337	1594	818	1284
1968	1123	996	943	799	542	142	65	112	309	559	976	1137
1969	1018	940	1202	730	384	325	26	54	238	911	932	1076
1970	1122	883	1132	789	390	183	136	42	395	724	893	1042
1971	797	1062	979	725	519	0	106	88	390	634	871	1087
1972	1082	912	763	628	452	67	104	124	296	618	1106	1212
1973	1226	992	985	870	486	86	105	39	323	509	804	1105
1974	1114	920	774	661	273	73	16	105	363	498	869	1165
1975	1110	1028	877	700	461	49	21	30	286	526	943	942
Average:	1095	1047	957	693	396	134	58	96	305	670	872	1102

Total Annual Average: 7425

DEGREE DAY (Definition) - A unit, based upon temperature difference and time, used in estimating fuel consumption and specifying nominal heating load of a building in winter. For any one day, when the mean temperature is less than 65°F, there exists as many degree days as there are Fahrenheit degrees difference in temperature between the mean temperature for the day and 65°F. (ASHRAE)

APPENDIX B

CALCULATED HEAT LOSS FOR TYPE 12 QUARTERS,

UNITED STATES AIR FORCE ACADEMY

APPENDIX B

CALCULATED HEAT LOSS FOR TYPE 12 QUARTERS

UNITED STATES AIR FORCE ACADEMY

BASIC DATA

Inside Design Temperature = $T_i = 70^{\circ}F$

Outside Design Temperature = $T_o = -2^{\circ}F$

Degree Days = 7425

Coefficients of Thermal Transmission (BTU's/Hr-Ft^2 - $^{\circ}F$)

Wood Floors (Crawlspace $T_o = 20^{\circ}F$)	U = 0.31
Window Inserts	U = 0.86
Peaked Roofs	U = 0.064
Flat Roofs	U = 0.069
Glazing (+ Storm)	U = 0.56
Brick Walls	U = 0.10
B&B Walls	U = 0.11
Basement Walls (Assume $T_o = 32^{\circ}F$)	U = 0.10
Basement Floor (Assume $T_o = 50^{\circ}F$)	U = 0.10
Doors (+ Storm)	U = 0.33

Room/ Space	Structural Component	Area/ Crack L	U	ΔT	Heat Load (BTU/HR)	Totals (BTU/HR)
Entry	Floor	44	0.31	50	682	
	Ceiling	44	0.069	72	219	
	B&B Wall	6	0.11	72	47	
	Glazing	56	0.56	72	2258	
	Panels	0	0.86	72	ø	
	Door	21	0.33	72	499	
	$Infilt_D$	20	1.00	72	1440	
	$Infilt_W$	42	0.50	72	1512	6657
Living Room	Floor	270	0.31	50	4185	
	Ceiling	270	0.069	72	1341	
	Brick Wall	132	0.10	72	950	
	B&B Wall	128	0.11	72	1014	
	Glazing	84	0.56	72	3387	
	Panels	0	0.86	72	ø	
	Infilt	63	0.50	72	2268	13,145
Kitchen	Floor	104	0.31	50	1612	
	Ceiling	104	0.069	72	517	2129
Dining Room	Floor	104	0.31	50	1612	
	Ceiling	104	0.069	72	517	
	B&B Wall	16	0.11	72	127	
	Glazing	56	0.56	72	2258	
	Panels	0	0.86	72	ø	
	Door	17	0.33	72	404	
	$Infilt_D$	17	1.00	72	1224	
	$Infilt_W$	42	0.50	72	1512	7654
Bath #1	Floor	40	0.31	ø	ø	
	Ceiling	40	0.069	72	199	
	B&B Wall	40	0.11	72	317	516
Bath #2	Floor	40	0.31	ø	ø	
	Ceiling	40	0.069	72	199	199
Master Bedroom	Ceiling	192	0.069	72	954	
	Floor	192	0.31	0	ø	
	Brick Wall	128	0.10	72	922	
	B&B Wall	36	0.11	72	253	
	Glazing	40	0.56	72	1613	
	Panels	16	0.86	72	991	
	Infilt	42	0.50	72	1512	6245

Room/ Space	Structural Component	Area/ Crack L	U	ΔT	Heat Load (BTU/HR)	Total (BTU/HR)
Hall/ Stairs	Floor	120	0.31	0	ø	
	Ceiling	120	0.069	72	596	
	Brick Wall	48	0.10	72	346	942
Bedroom #2	Floor	130	0.31	0	ø	
	Ceiling	130	0.069	72	646	
	Brick Wall	180	0.10	72	720	
	B&B Wall	16	0.11	72	127	
	Glazing	40	0.56	72	1623	
	Panels	16	0.86	72	991	
	Infilt	42	0.50	72	1512	5619
Bedroom #3	Same as Bedroom #2					5619
Basement	Floor	720	0.10	20	1440	
	Walls	112	0.10	38	426	1866

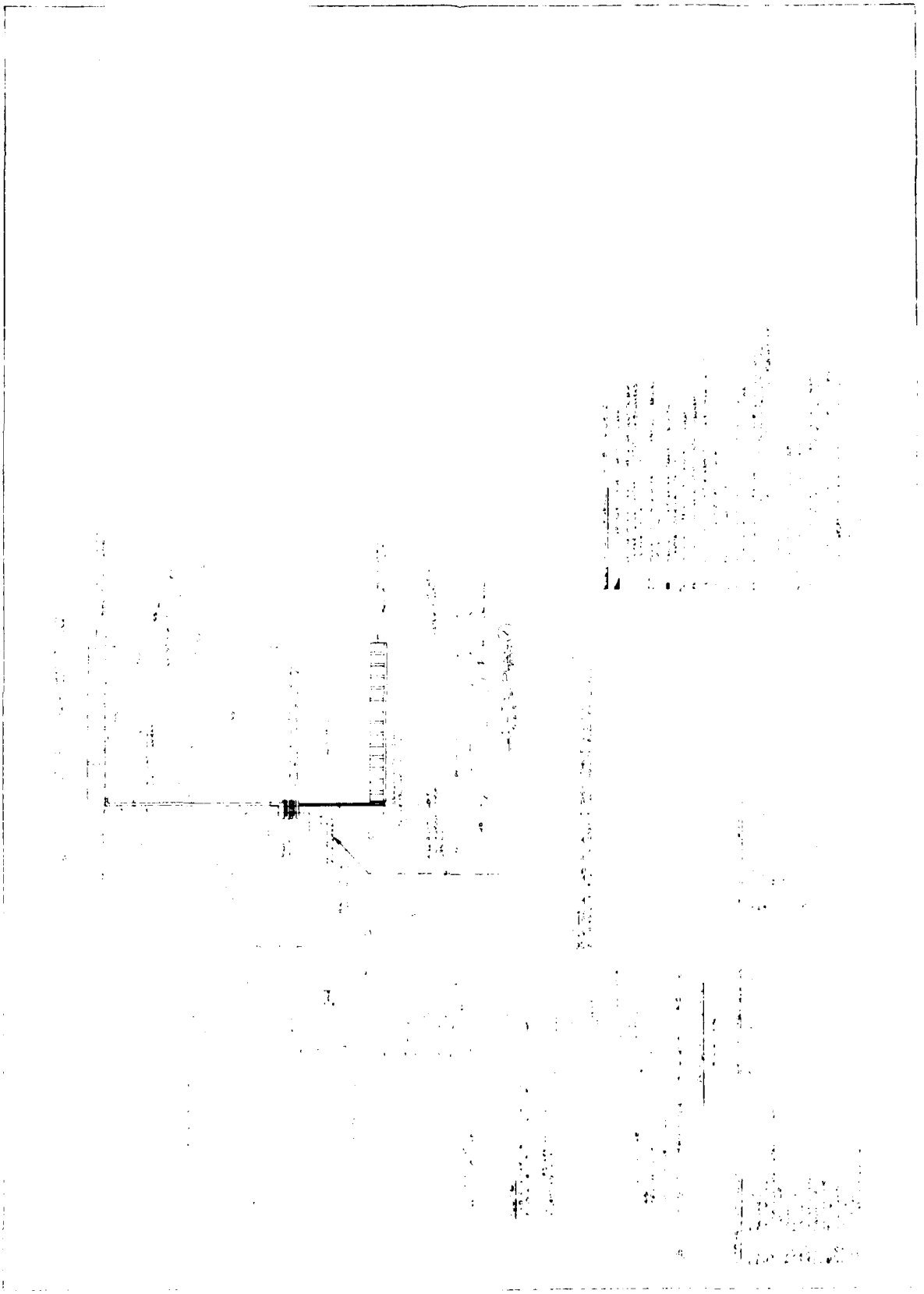
GRAND TOTAL: 50,591 BTU/Hr

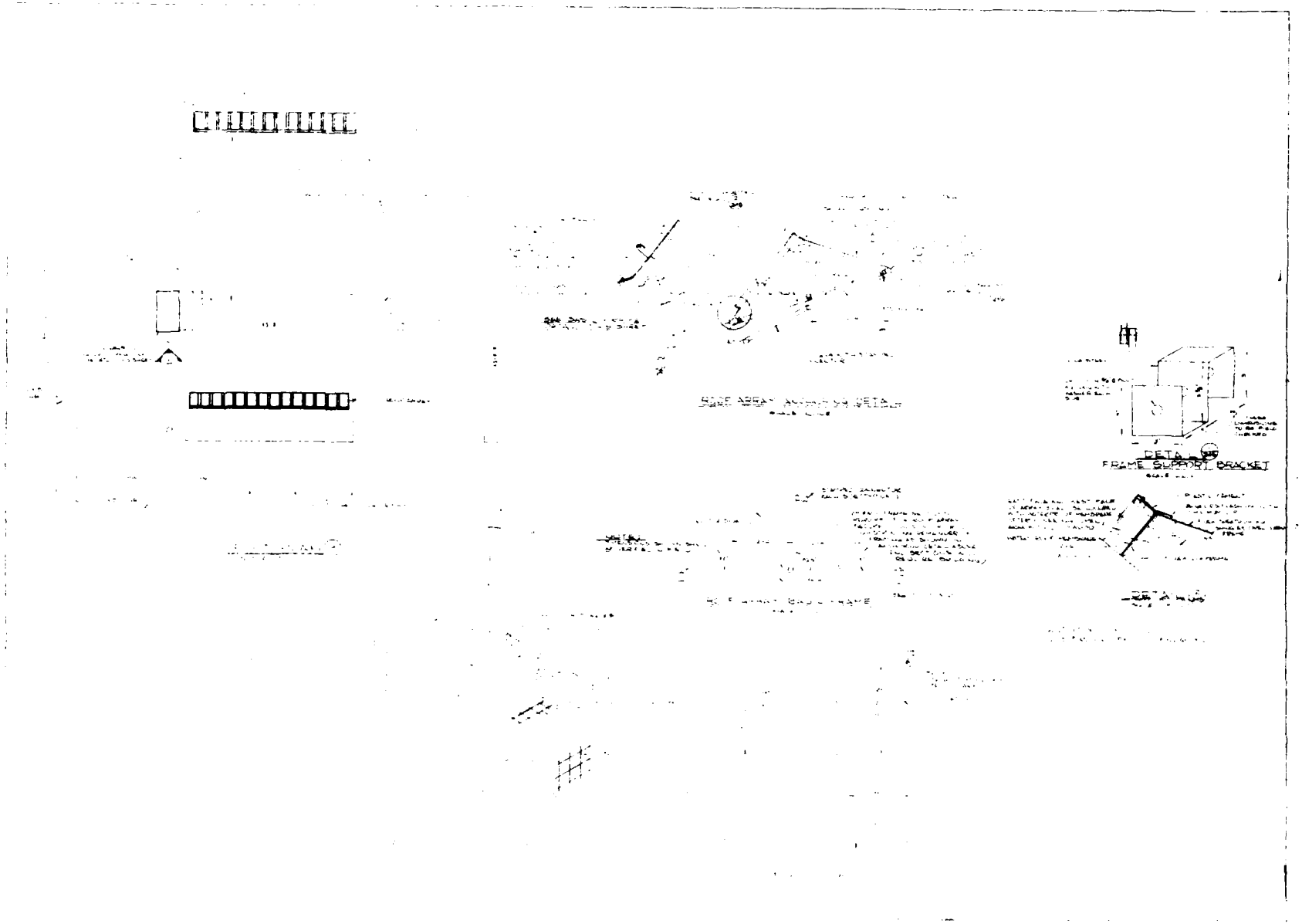
APPENDIX C

USAFA SOLAR TEST HOUSE AS-BUILT

CONSTRUCTION DRAWINGS

SHEET NO.	TITLE	PAGE NO.
1 of 6	Site Plan, Plot Plans, Details	C-2
2 of 6	Storage Tank, Roof Array, Plans, Details and Elevations	C-3
3 of 6	Ground Array, Plans, Details and Elevations	C-4
4 of 6	Mechanical Plans and Details	C-5
5 of 6	Instrumentation and Controls	C-6
6 of 6	Electrical Details and Elevations	C-7

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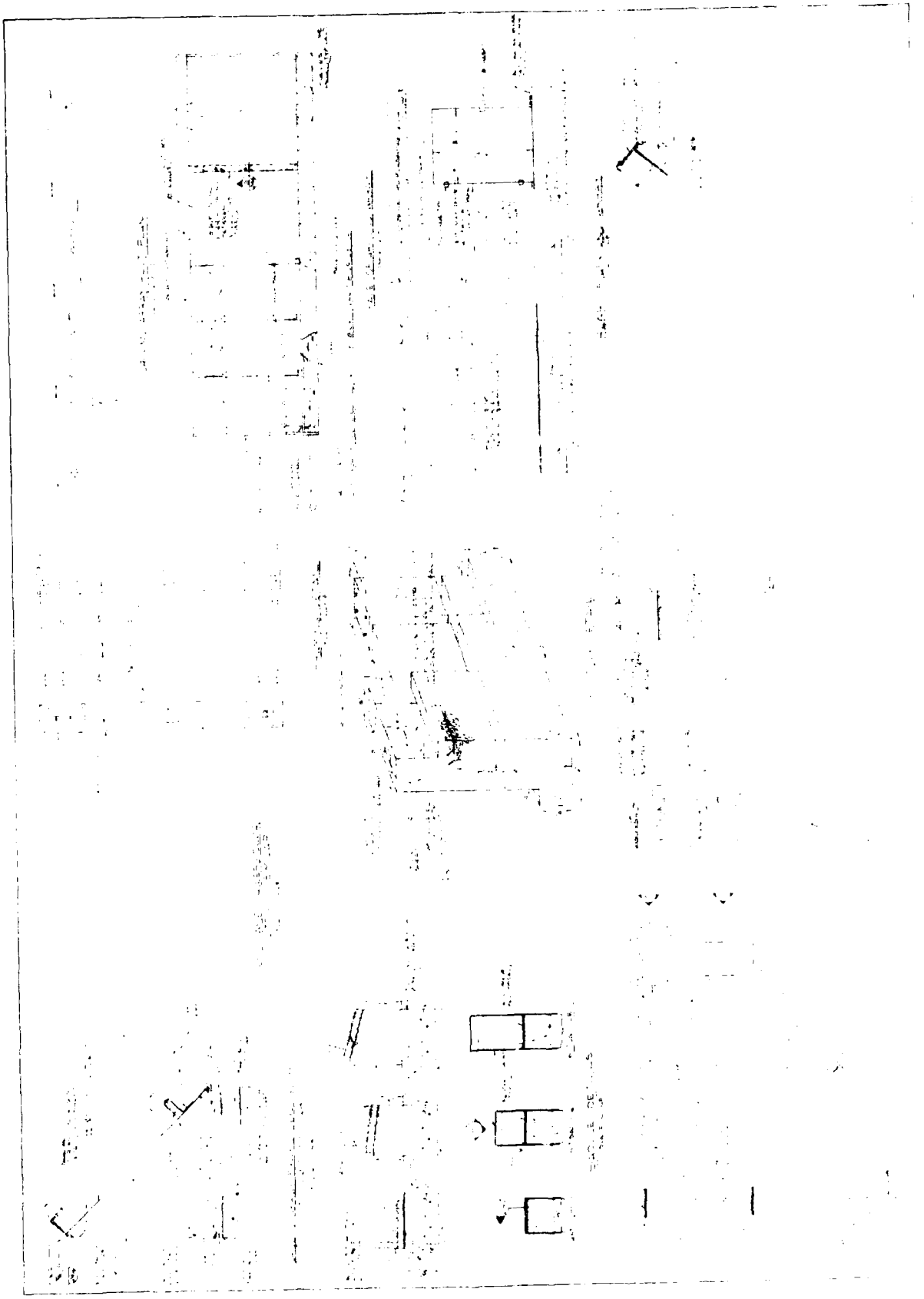

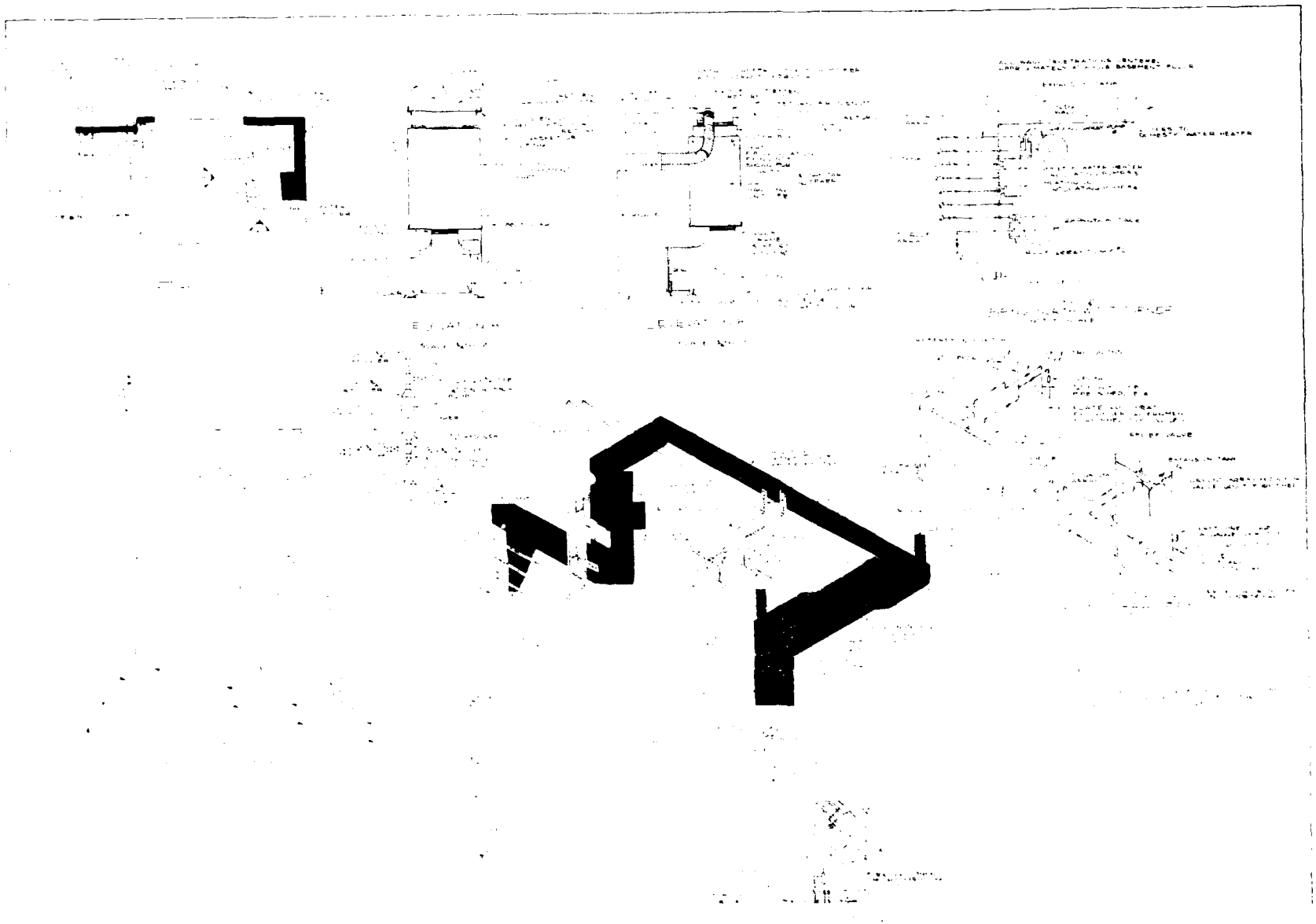

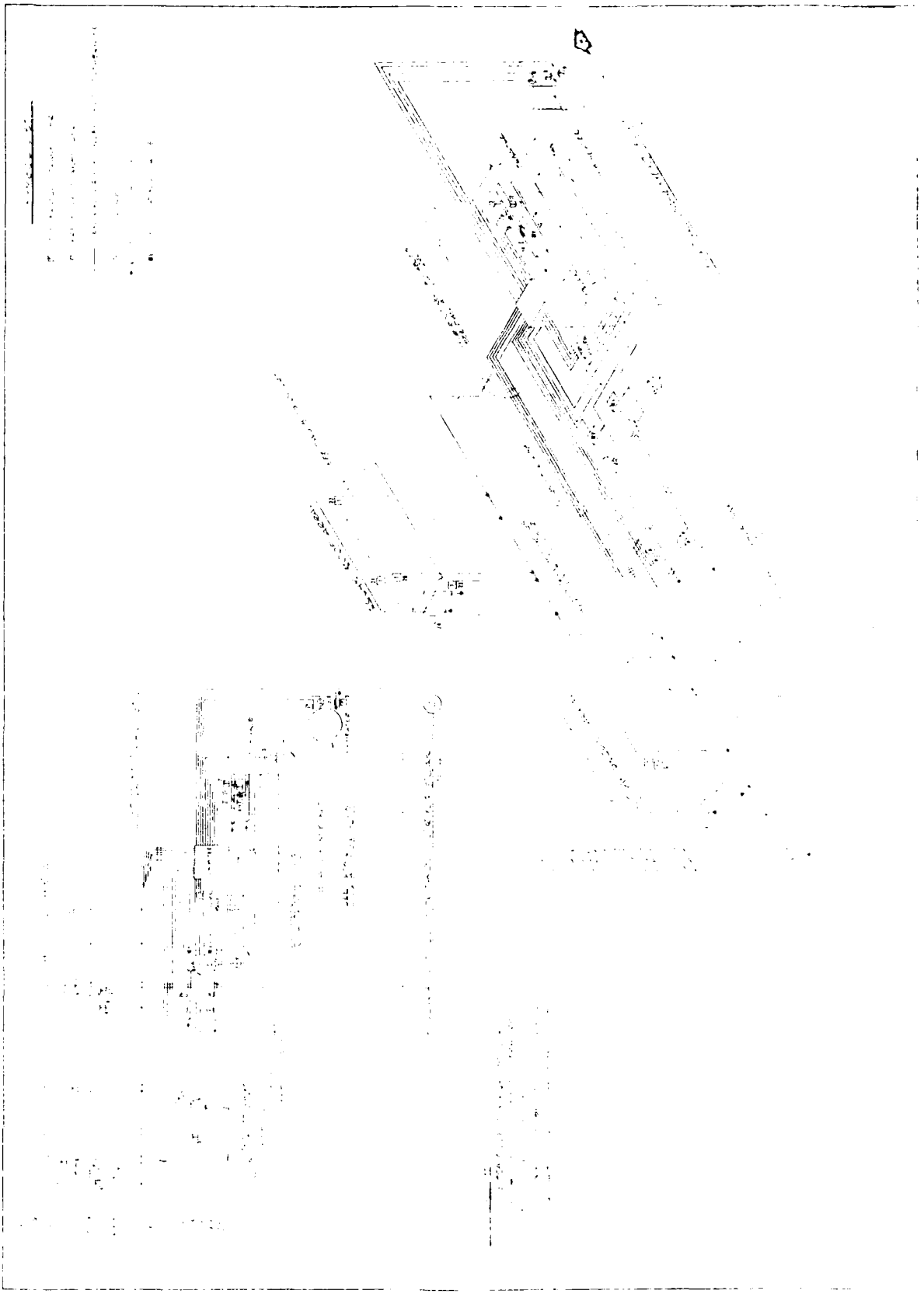

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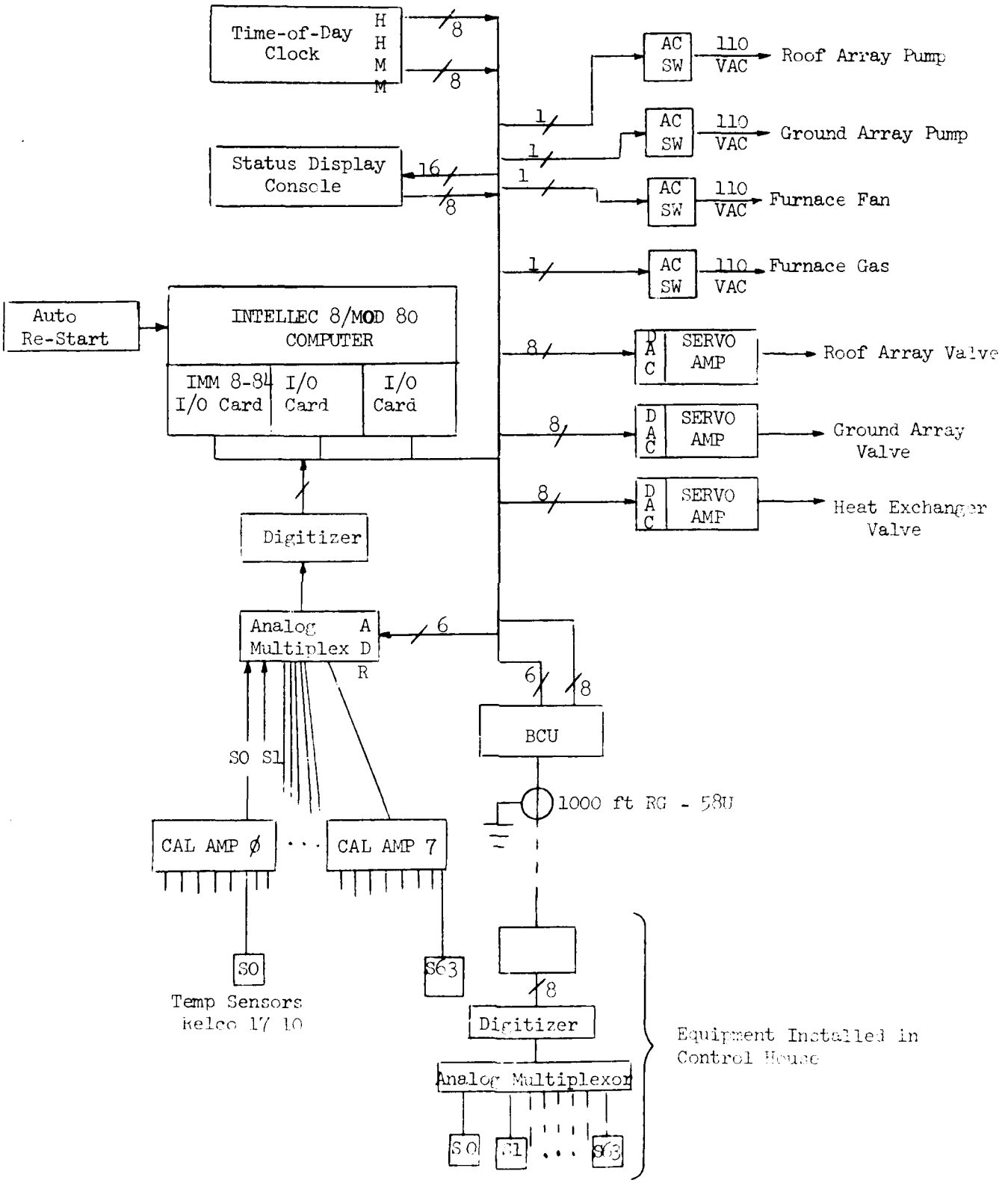
APPENDIX D

INSTRUMENTATION AND CONTROL SYSTEM FLOW CHARTS, BLOCK DIAGRAMS AND CIRCUIT SCHEMATIC DIAGRAMS

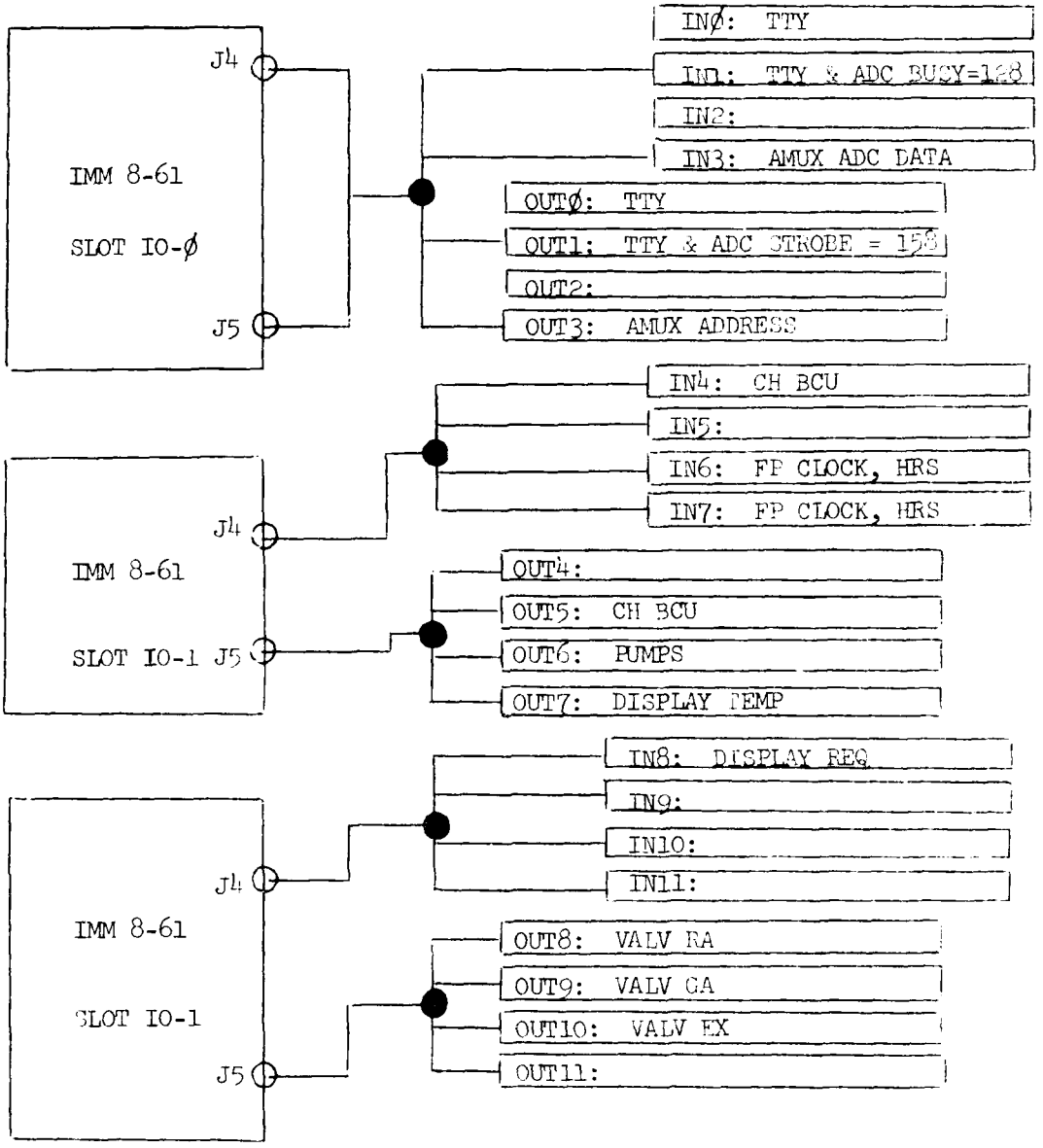
TITLE	PAGE NO.
ICS Hardware Overview	D-3
Microcomputer I/O Channelization	D-4
Sensor Cross Reference	D-5
Sensor Multiplexing Scheme	D-8
Sensor Terminating Strip Connections	D-9
Digitizer Board Wiring Overview	D-10
Control House Remote Controller Circuit Diagram	D-11
Control House Digitizer	D-12
Interface of Analog Multiplexer	D-13
Analog Multiplexer Connectors	D-14
Analog Multiplexer Circuit Diagram	D-15
Status Display Interface	D-16
Status Display Console Encoder Circuit Diagram	D-17
Interface to Clock	D-18
Solar Test House Clock Block Diagram	D-19
Interface to Pumps and Motor Control Switches	D-20
Pump and Valve Barrier Strip	D-21
Interface to Valve Modulators	D-22
Dew Point Sensor Interface Adaptor	D-23

TITLE	PAGE NO.
Wind Speed/Direction Interface Adaptor	D-24
Pyranometer Interface Adaptor	D-25
Valve Control Interface Adaptor	D-26
Flow Sensor Interface Adaptor	D-27
Furnace Gas and Gas Control Scheme	D-28
Computer Control Program Flow Charts:	
OUTPUT D-29	RTMSG D-33
TASKS D-30	TTYOUT D-34
INCP D-31	MOVED D-35
BUFFIL D-32	INSH D-36
PRINT D-33	INSHL D-37
	DLY1S D-38
	DLY1MS D-39

ICS Hardware Overview



Microcomputer I/O Channelization



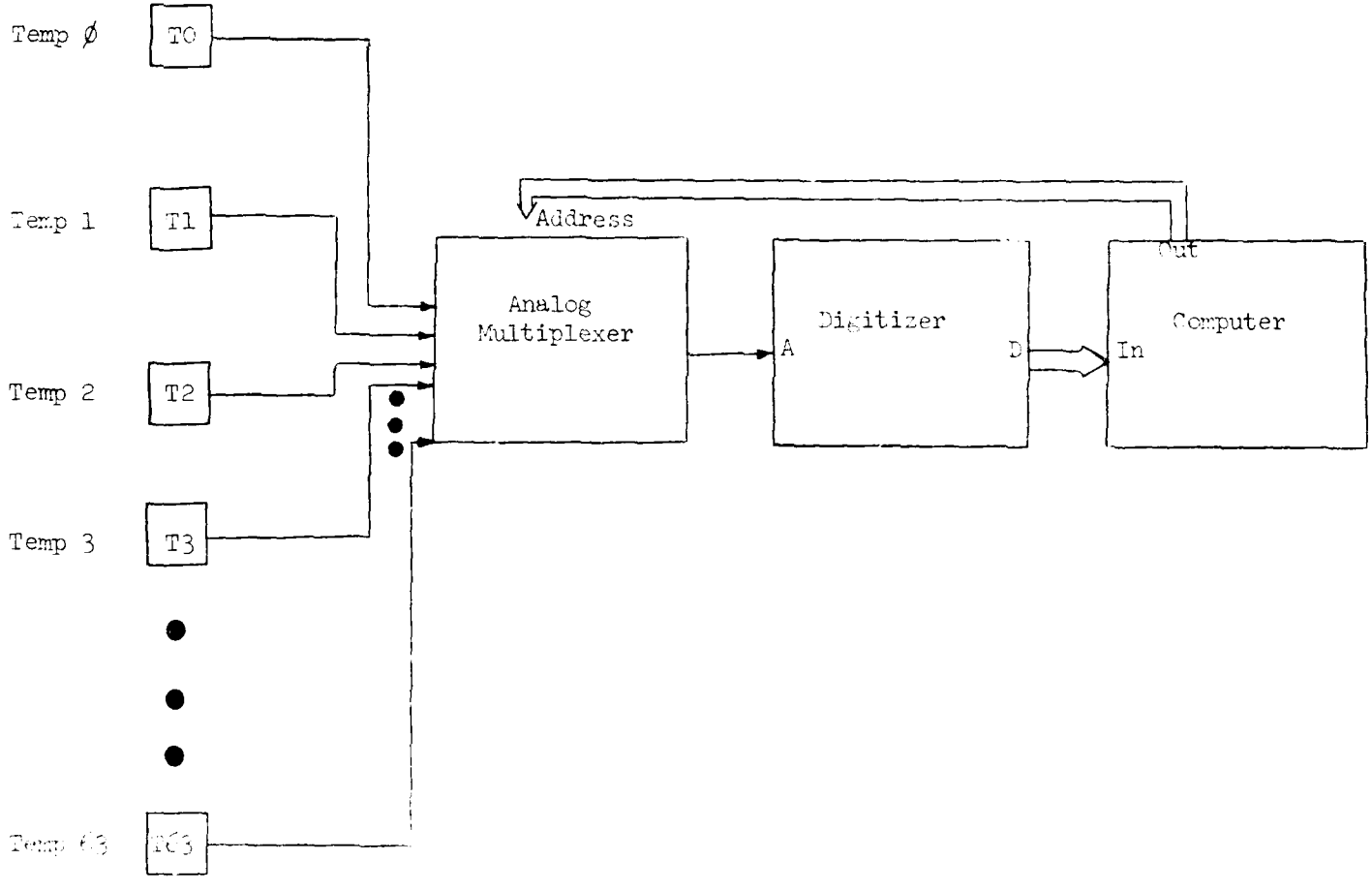
TTY BLOCK	PROGRAM LABEL	AMUX CHAN (DEC)	RAM LOCATION (HEX)	FUNCTION
GA	T0	0	100	Temp on outer glass surface
	T1	1	101	Temp on collector surface
	T2	2	102	Temp on collector surface (east end)
	T3	3	103	Water temp out of ground array
	T4	4	104	Water temp into ground array
TNK	T5	5	105	Storage tank water temp
RA	T20	20	114	Temp on outer glass surface
	T21	21	115	Temp on collector surface
	T22	22	116	Temp on collector surface (east end)
	T23	23	117	Water temp out of roof array
	T24	24	118	Water temp into roof array
SUN	T25	25	166	Pyranometer
HT	T06	06	106	Storage tank outside surface temp
	T7	7	107	Storage tank outside of insulation temp
	T8	8	108	Pre-heat hot water inlet temp
	T9	9	109	Pre-heat hot water outlet temp
	T10	10	10A	Living area control temp
	T11	11	10B	Living area requested temp
	T12	12	10C	Furnace heating coil inlet water temp

SENSOR CROSS-REFFRENCE

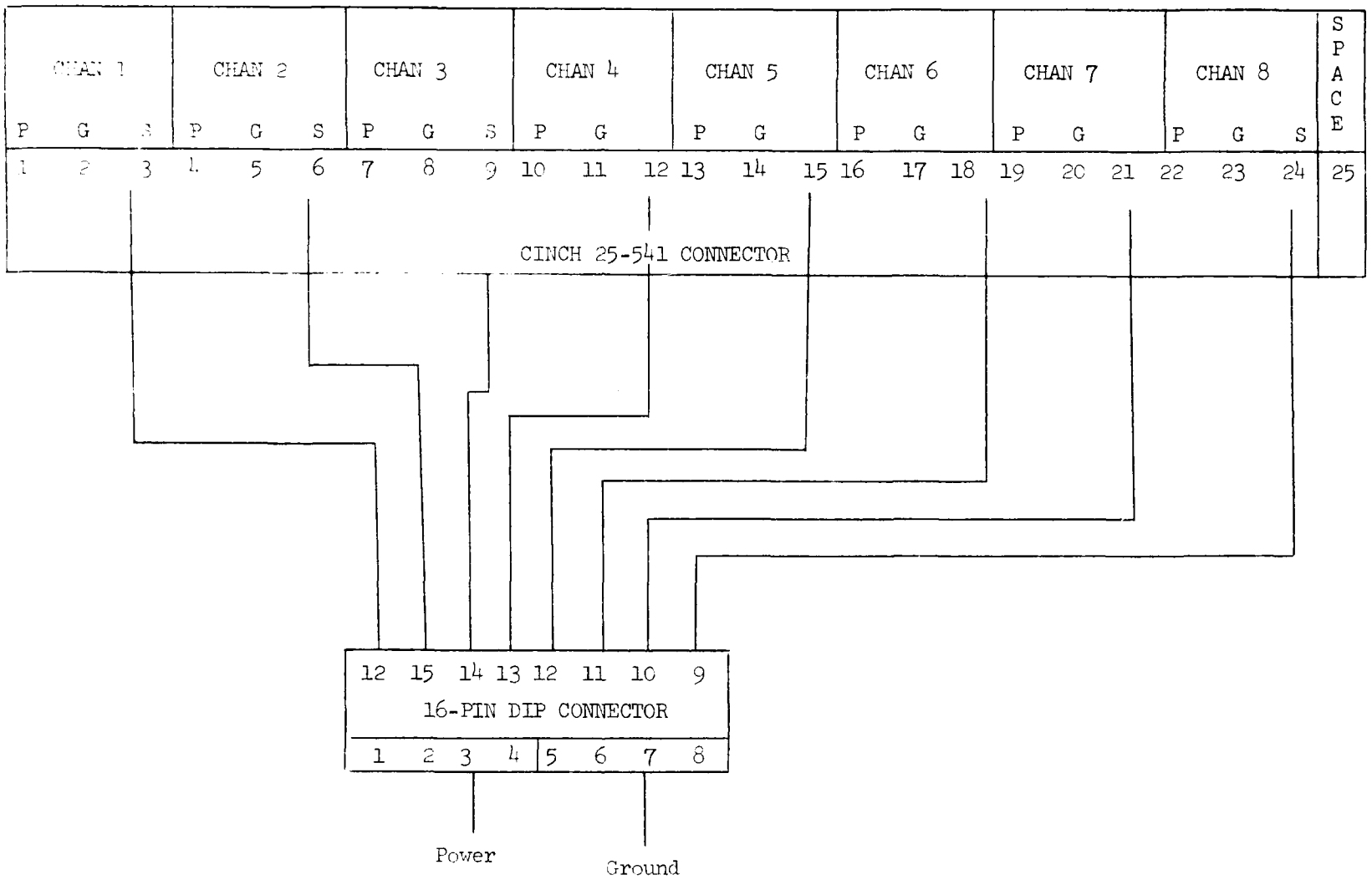
TTY BLOCK	PROGRAM LABEL	AMUX CHAN (DEC)	RAM LOCATION (HEX)	FUNCTION
HT (Cont)	T13	13	10D	Furnace heating coil outlet water temp
	T14	14	10E	Furnace heating coil bypass water temp
	T15	15	10F	Furnace heating coil air temp
LA	T30	30	11E	Temps inside test house
	T31	31	11F	
	T32	32	120	
	T33	33	121	
	T34	34	122	
	T35	35	123	
	T36	36	124	
CH	T40	BCU 1	1284	Temps inside control home
	T41	BCU 2	129	
	T42	BCU 3	12A	
	T43	BCU 4	12B	
	T44	BCU 5	12C	
	T45	BCU 6	12D	
	T46	BCU 7	12E	
FLO	(6A)	48	130	GA
	(RA)	49	131	RA
	(COIL)	50	132	(Old heat coil)

TTY BLOCK	PROGRAM LABEL	AMUX CHAN (DEC)	RAM LOCATION (HEX)	FUNCTION
CTL	VALU GA	MA-(Out 9)	161	
	VALU RA	NA-(Out 8)	162	
	PUMP	NA-(Out 6)	163	
WX	WX	51	169	Temp
	WX + 1	52	16A	DEWPT
	WX +2	53	16B	Wind Dir
	WX + 3	54	16C	Wind Vel

Sensor Multiplexing Scheme



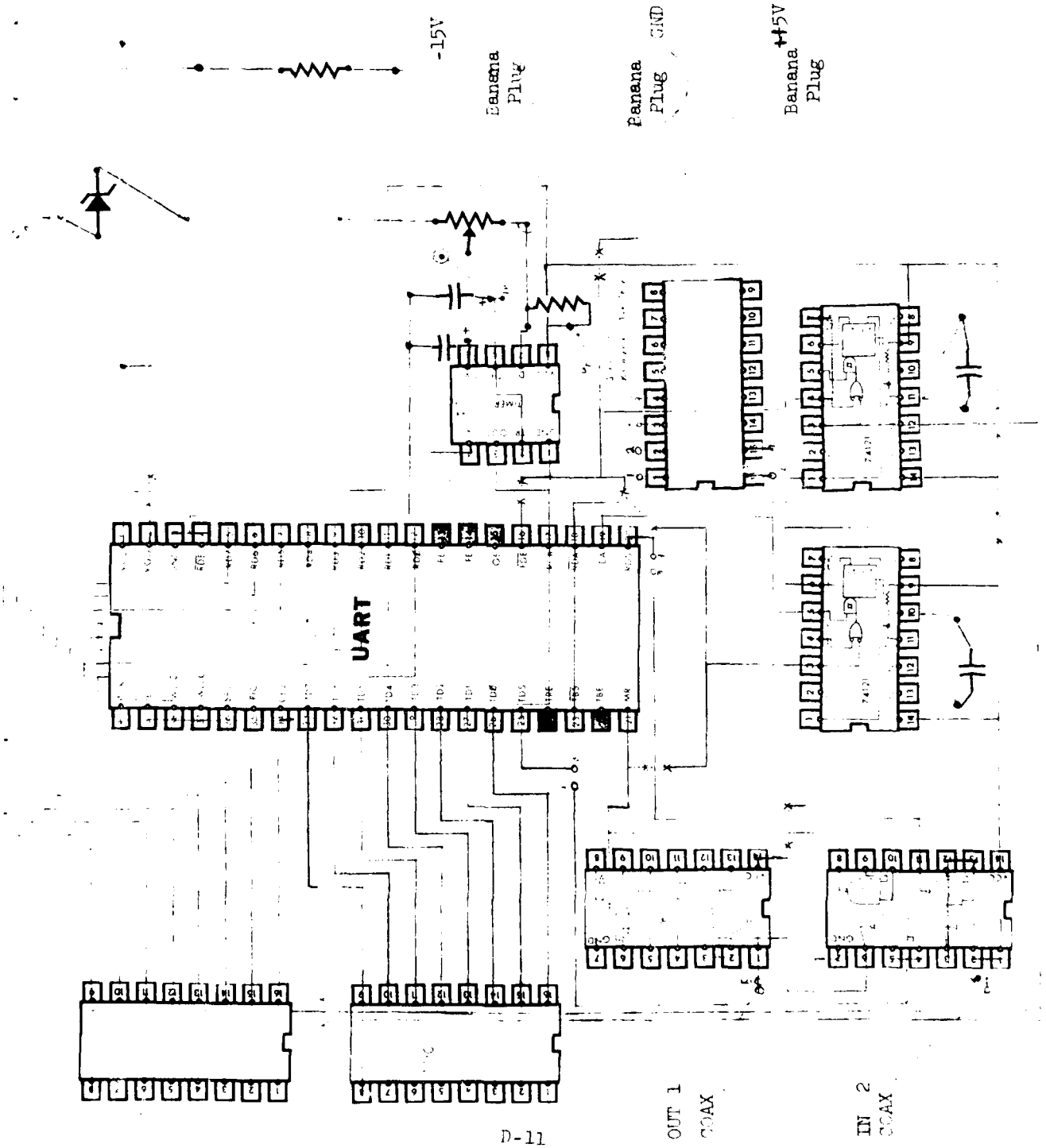
Sensor Termination Strip Connections



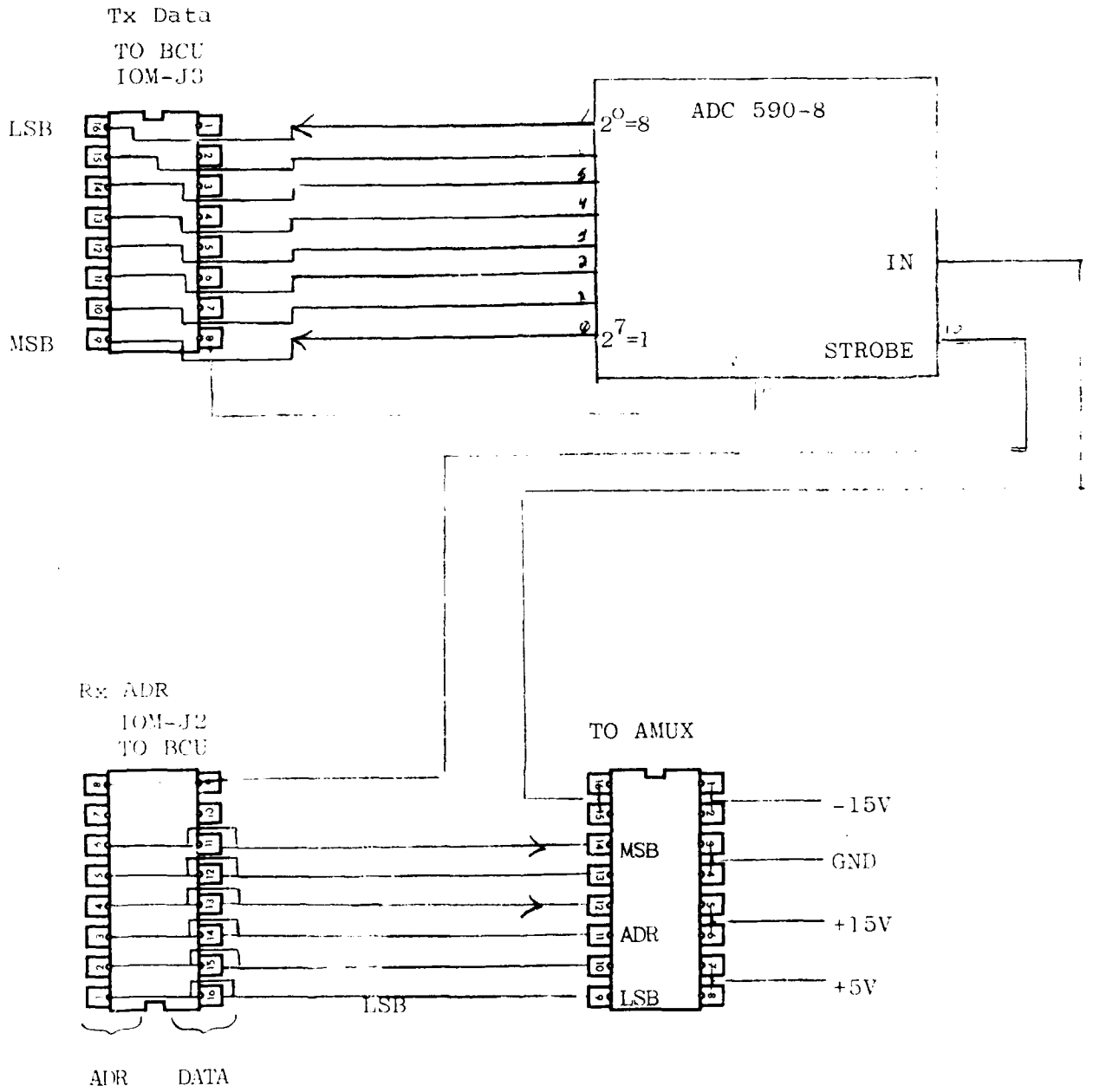
Sensor Terminating Strip (8 Chan)

DIGITIZER BOARD WIRING OVERVIEW

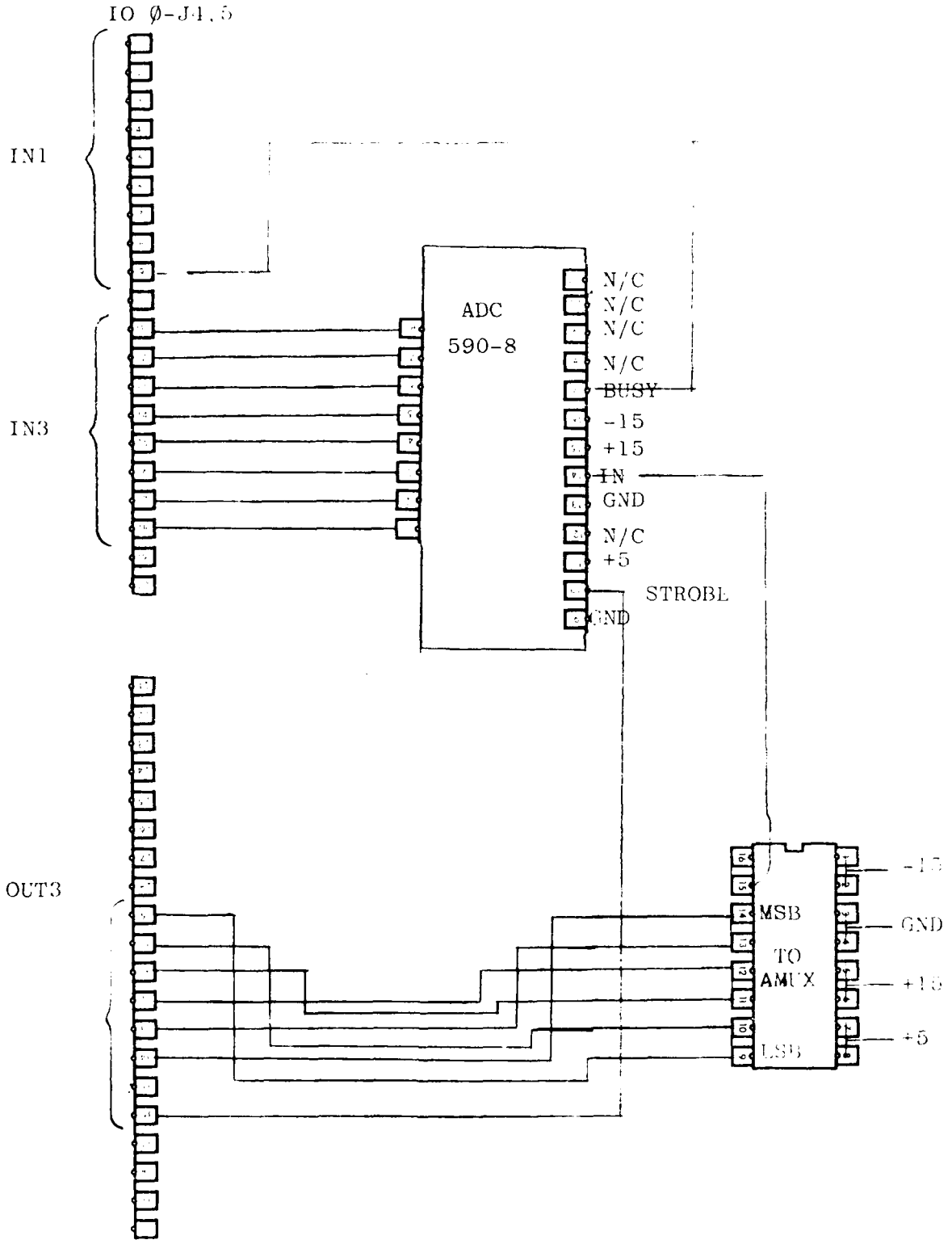
CONTROL HOUSE REMOTE CONTROLLER CIRCUIT DIAGRAM



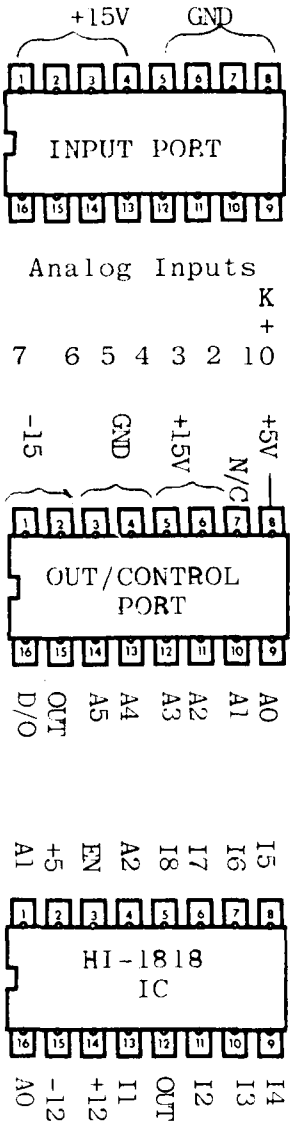
CONTROL HOUSE DIGITIZER



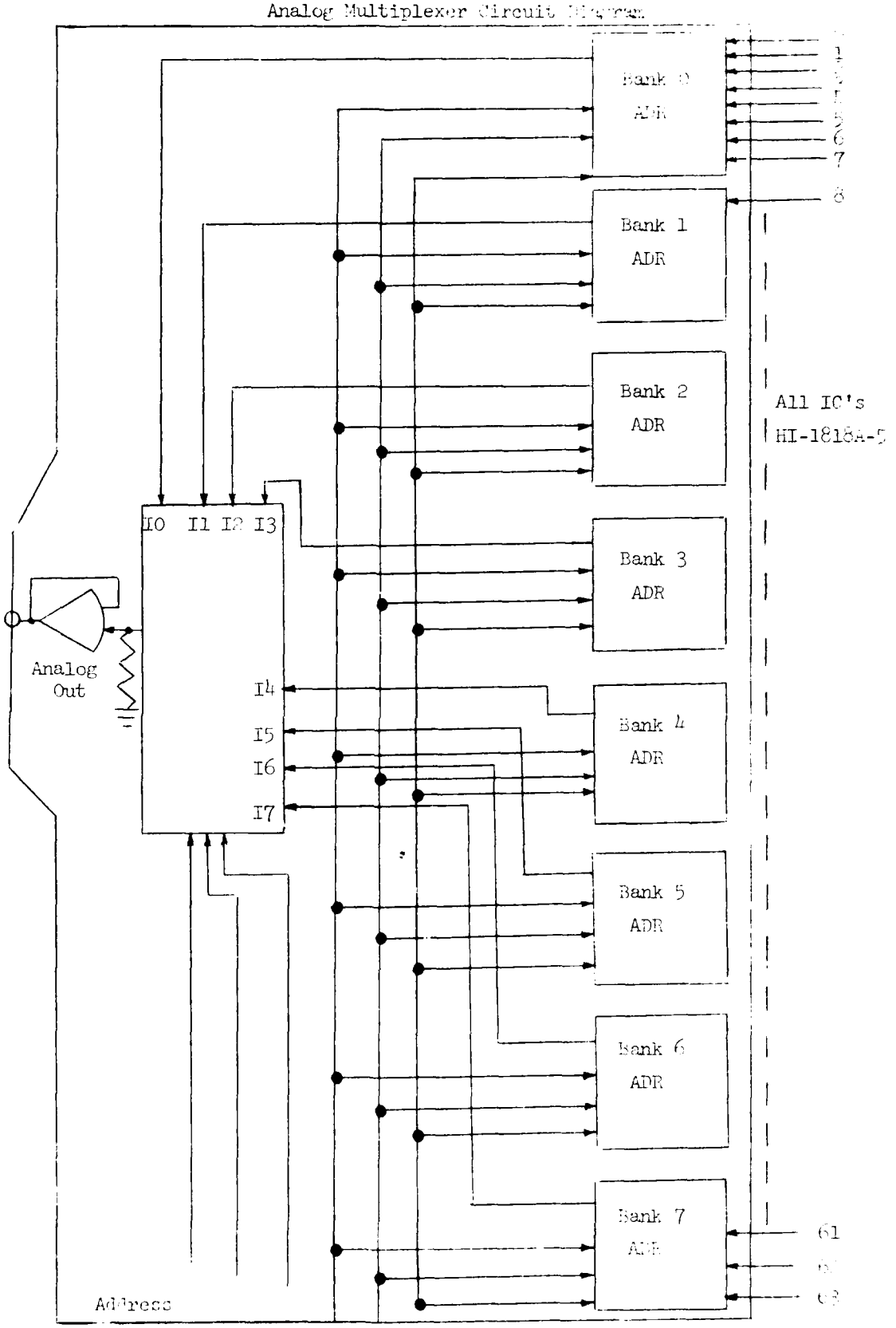
INTERFACE TO ANALOG MULTIPLEXER

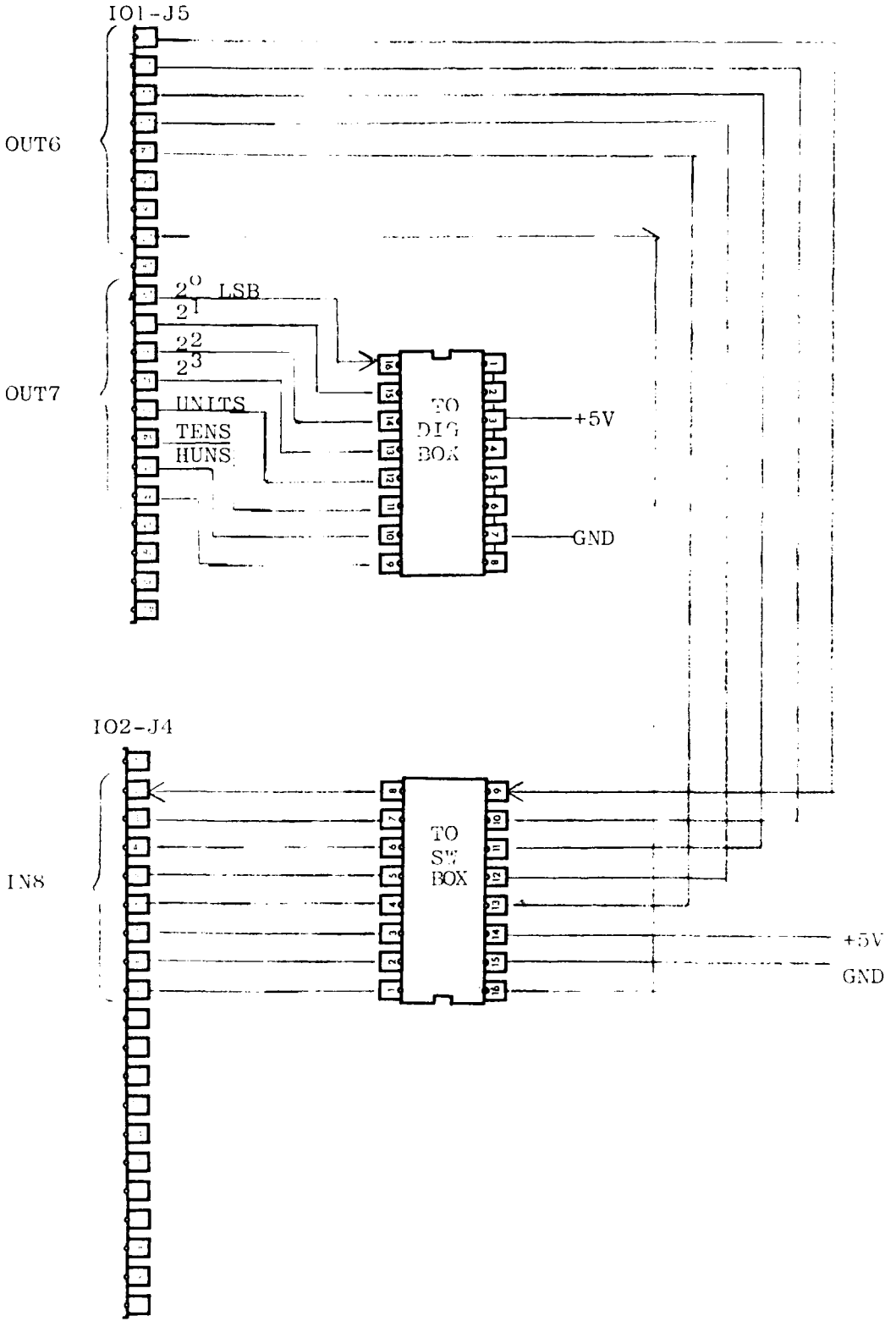


ANALOG MULTIPLEXER CONNECTORS

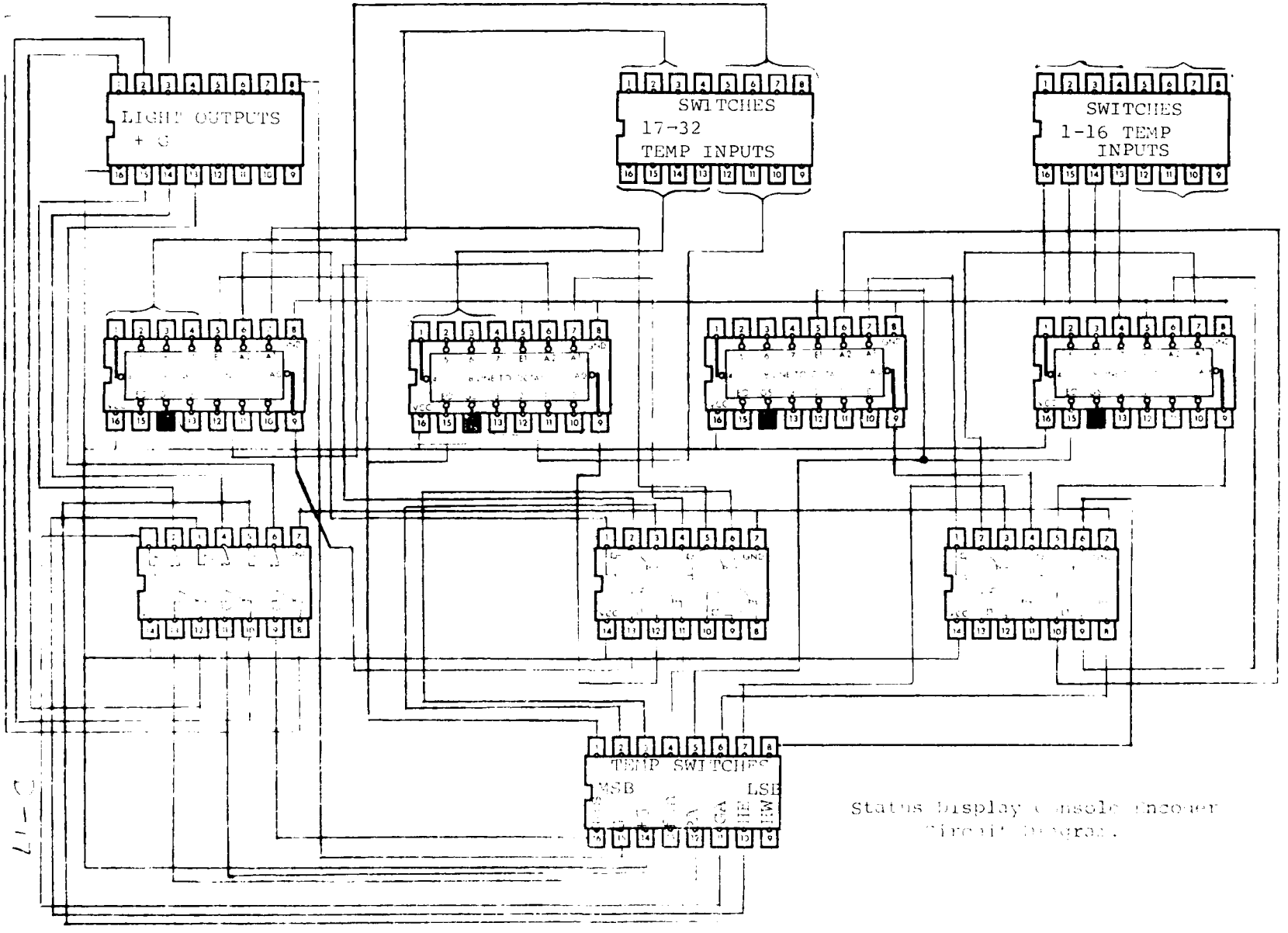


Analog Multiplexer Circuit Diagram



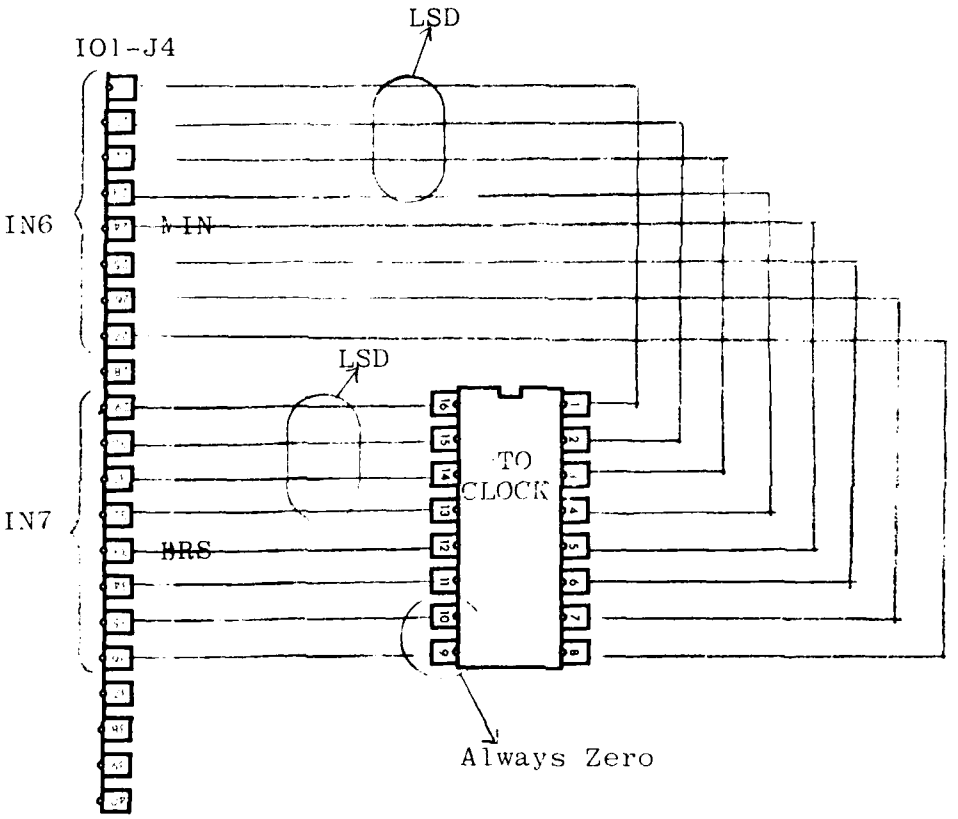


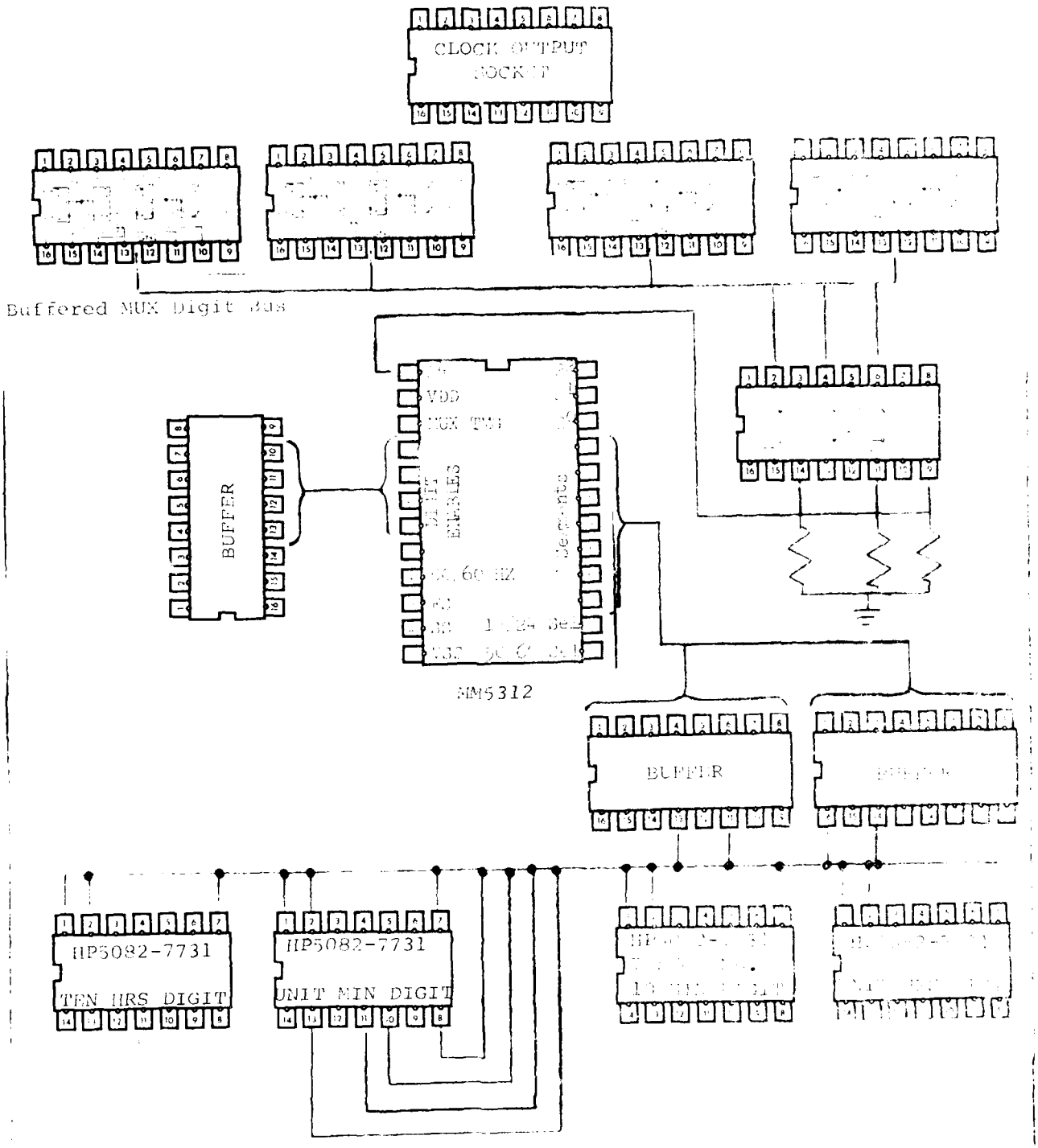
DISPLAY INTERFACE



Status Display Console Encoder
Circuit Diagram.

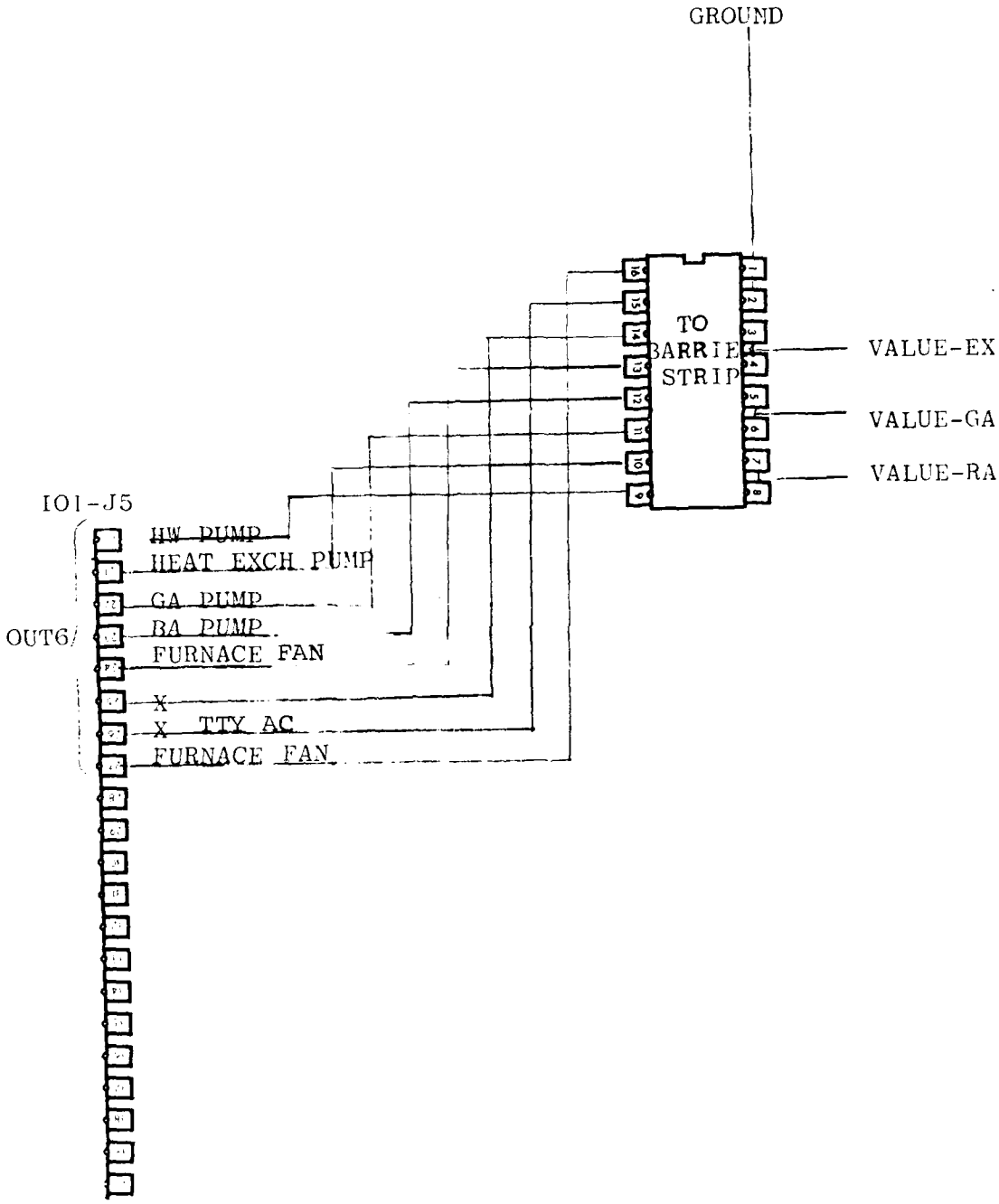
INTERFACE TO CLOCK

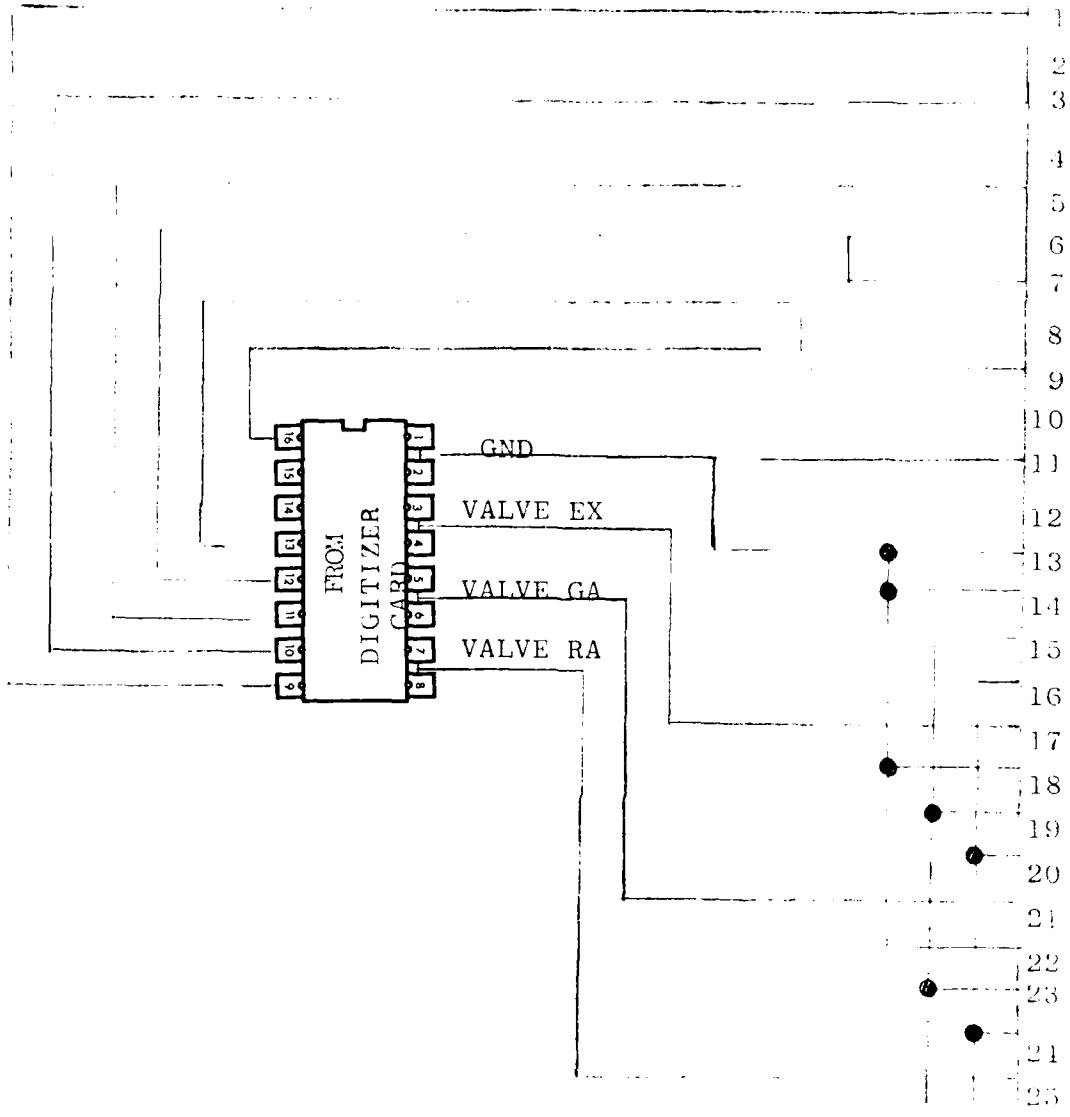




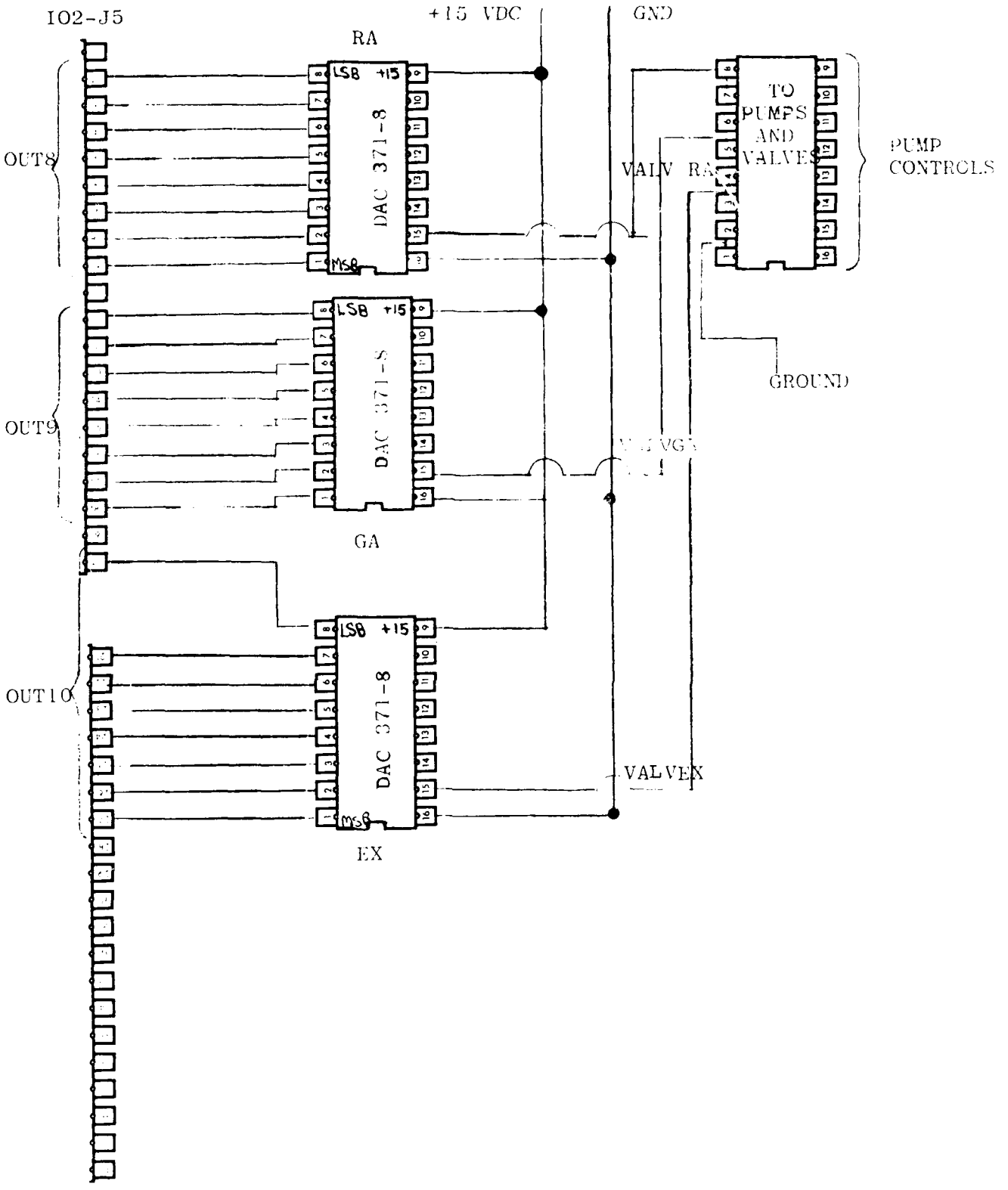
SOLAR TEST BOUS CLOCK BLOCK

Interface to Pumps and Motor Control Switches



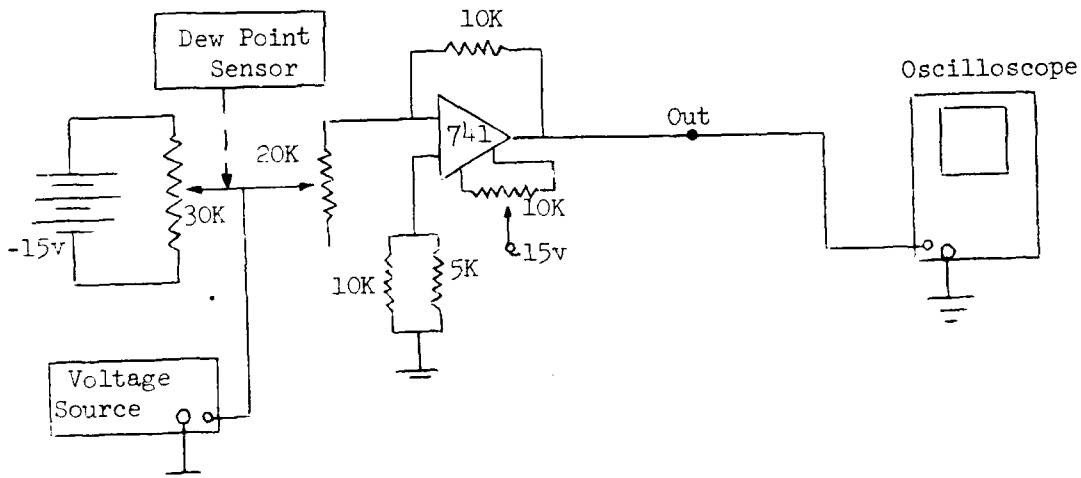


PUMP AND VALVE BARRIER STRIP



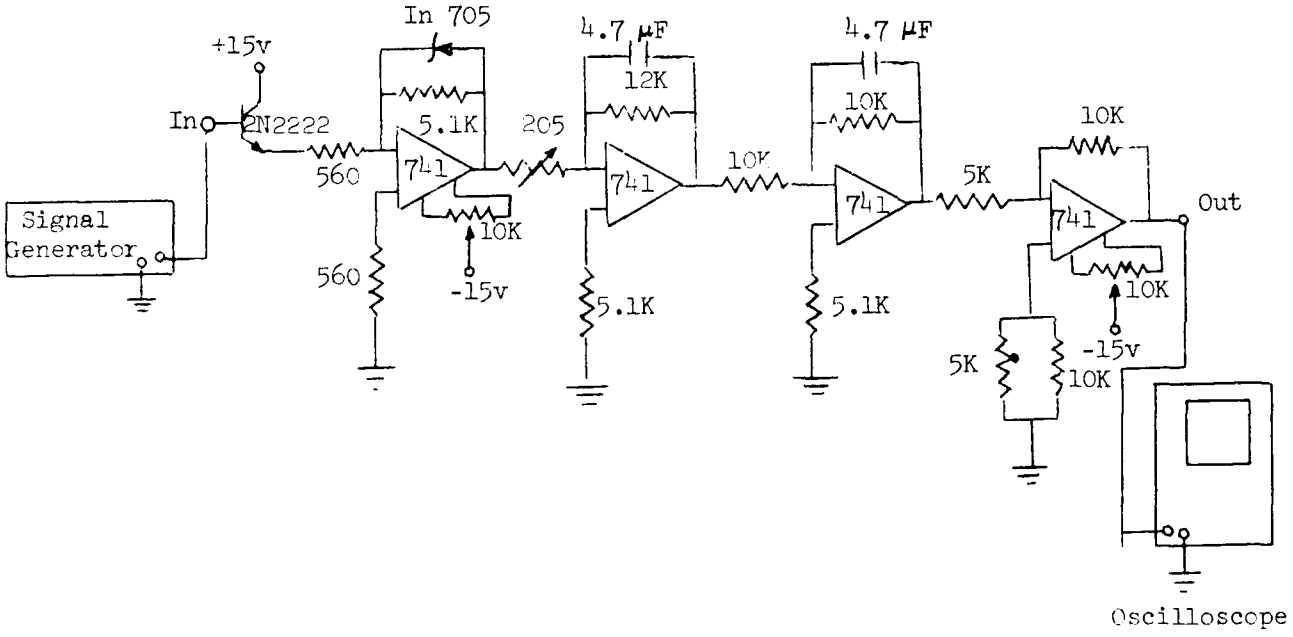
INTERFACE TO VALVE MODULATORS

Dew Point Sensor Interface Adaptor



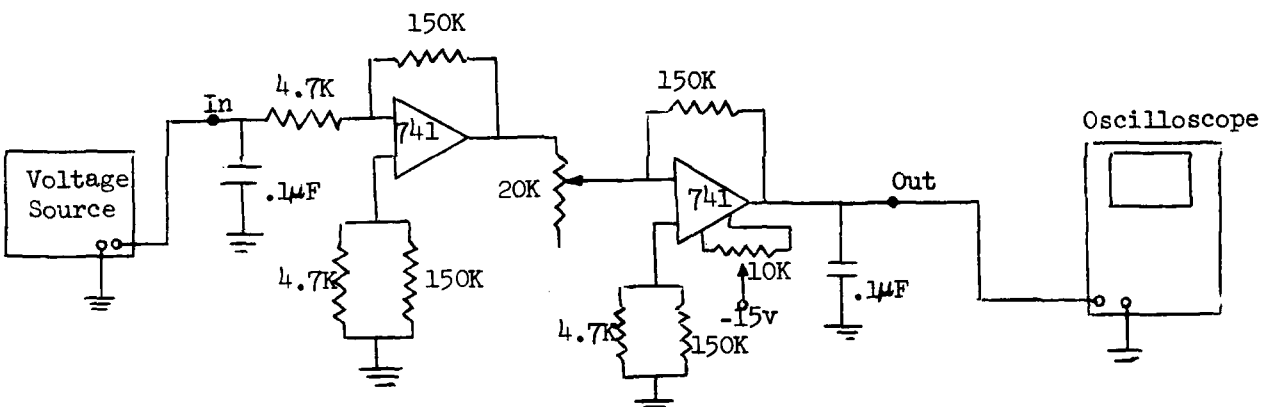
The dew point sensor interface circuit shown above is completed, mounted on a circuit board and has been tested. The device is to represent the dew point sensed by the existing equipment to the computer with an accuracy of $\pm$ .5°F. This represents an error voltage of not more than 0.2 volts at the output. When a known voltage was amplified by the circuit, as shown in the diagram above, the error was found to be less than 10 millivolts. This device was mounted inside the house within the existing equipment housing.

Wind Speed/Direction Interface Adaptor

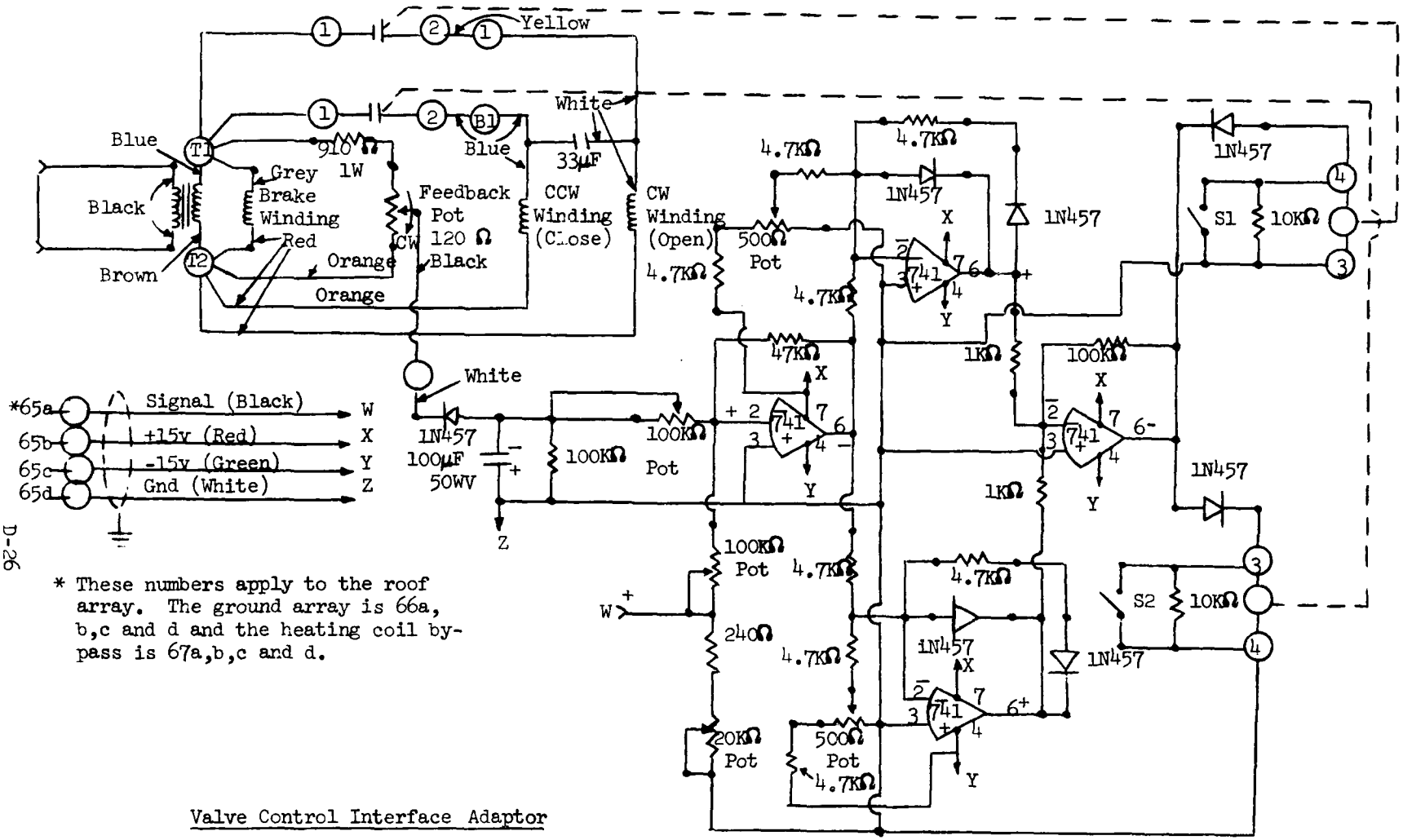


The wind speed/direction interface shown above is built and mounted on a circuit board and the device has been tested according to the illustrated scheme. The end item specifications for this device require that it be able to represent the wind speed and direction sensed by the instrumentation to within ± 5%. The circuit was tested by inputting a pulse train ranging in frequency from dc to 1500 Hz and with an amplitude of 7.5 volts. The output was found to be a dc voltage which varied with frequency.

Pyranometer Interface Adaptor

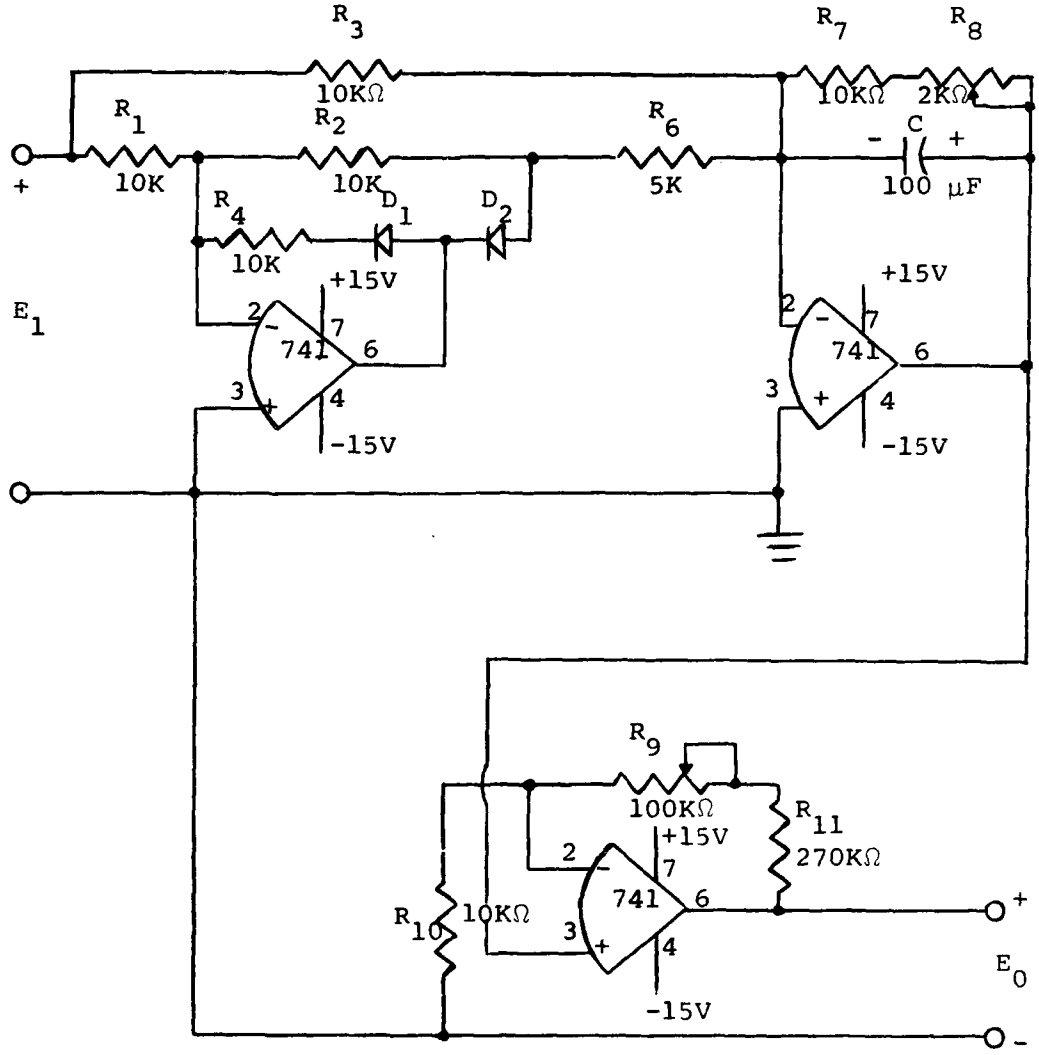


Above is the schematic of the pyranometer amplifier and its test setup. This device has been installed in the base of the pyranometer mounting. The circuit is capable of a gain of 1000; however, it has been set for a gain of about 500 so as to make conversion in the computer simpler. The circuit was tested by inputting voltages on the order of 1-8 millivolts and observing the output on the oscilloscope as shown above. The circuit displayed an accuracy of better than 0.1%.

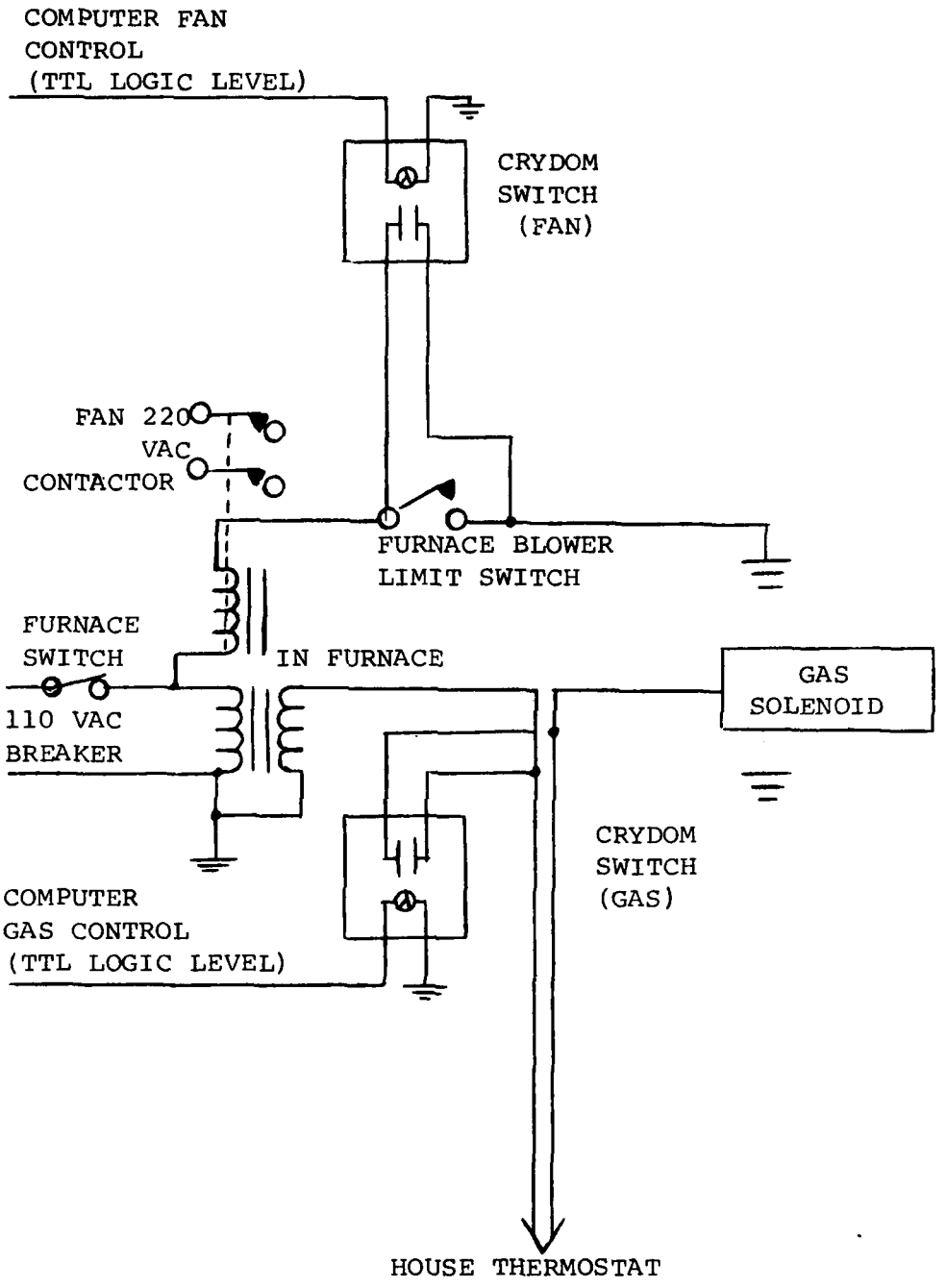


* These numbers apply to the roof array. The ground array is 66a, b,c and d and the heating coil by-pass is 67a,b,c and d.

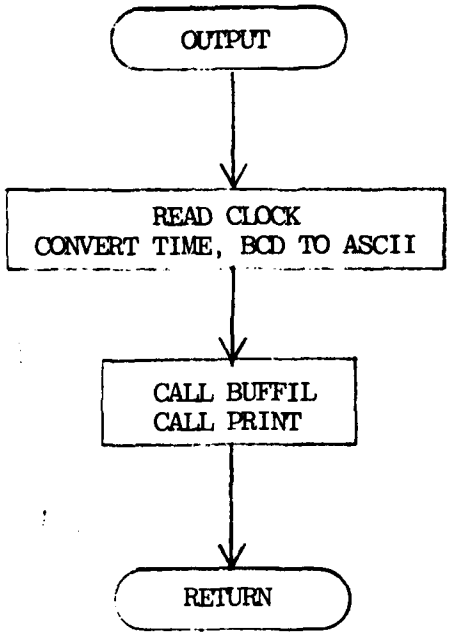
Valve Control Interface Adaptor

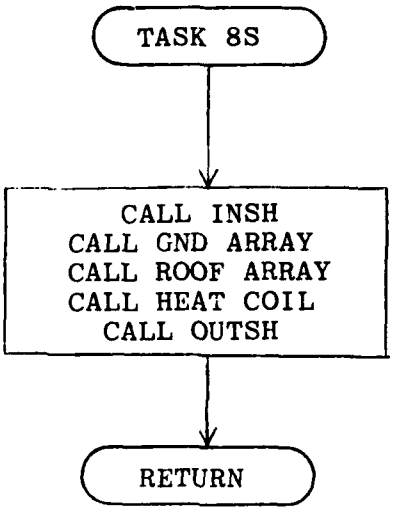


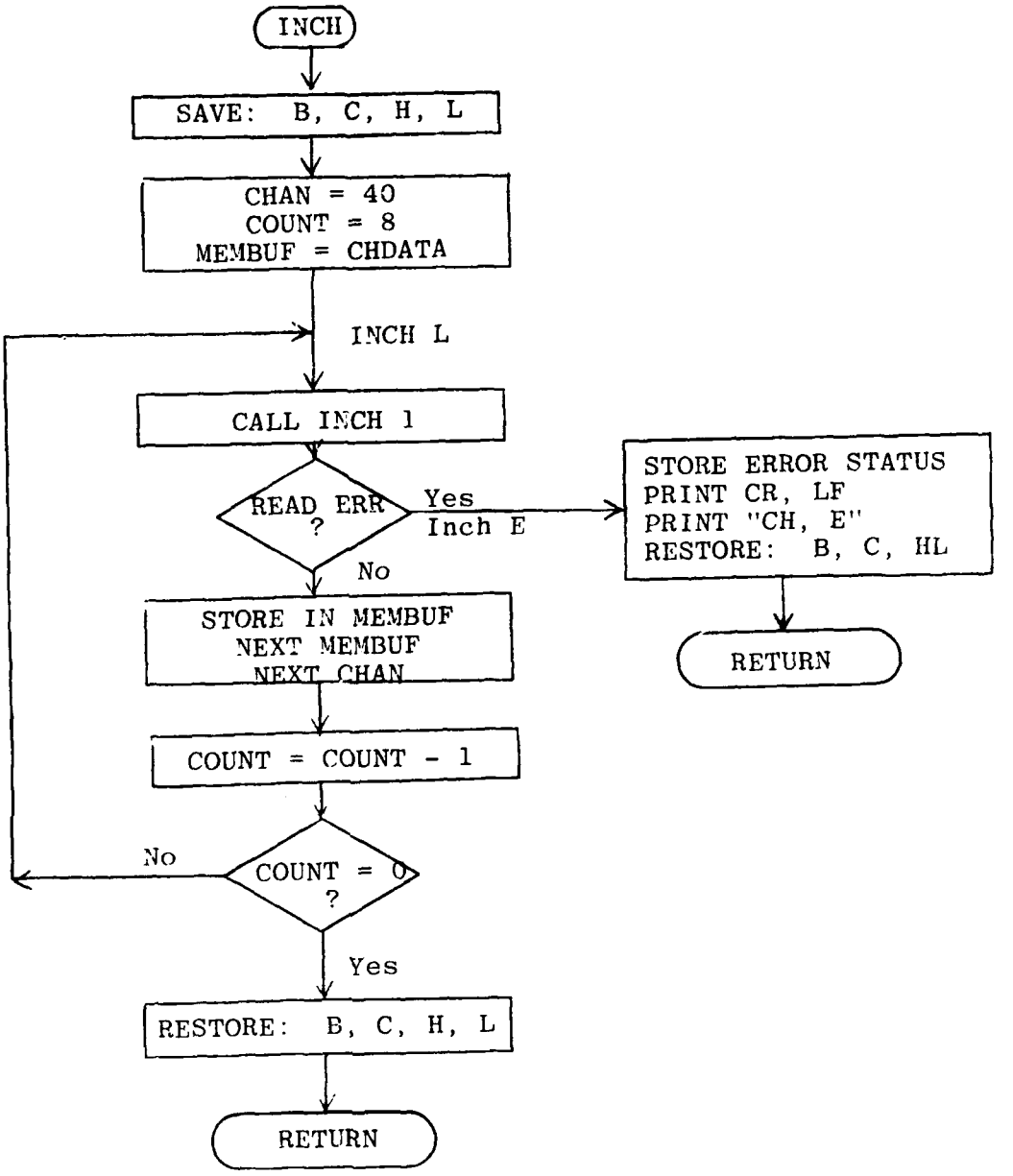
FLOW SENSOR INTERFACE ADAPTOR

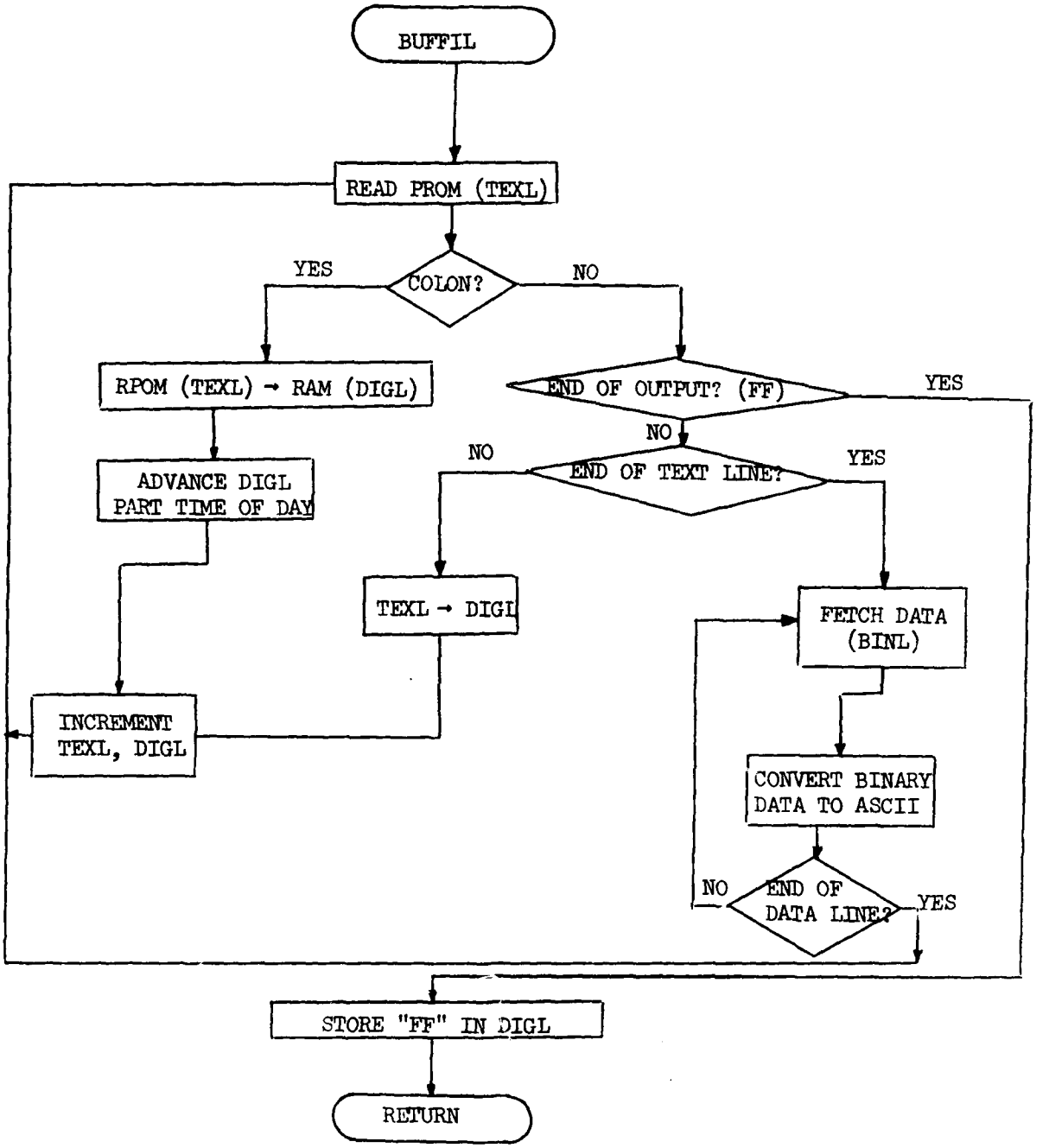


FURNACE GAS AND FAN CONTROL SCHEME

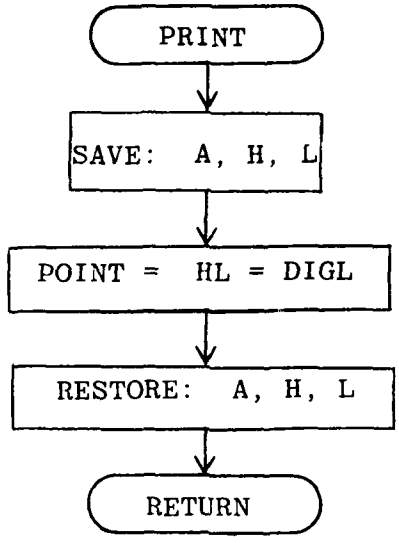

OUTPUT
READ CLOCK
CONVERT TIME, BCD TO ASCII
CALL BUFFIL
CALL PRINT
RETURN


TASK 8S
CALL INSH
CALL GND ARRAY
CALL ROOF ARRAY
CALL HEAT COIL
CALL OUTSH
RETURN


INCH
SAVE: B, C, H, L
CHAN = 40
COUNT = 8
MEMBUF = CHDATA
INCH L
CALL INCH 1
READ ERR ?
Yes
Inch E
No
STORE ERROR STATUS
PRINT CR, LF
PRINT "CH, E"
RESTORE: B, C, HL
RETURN
STORE IN MEMBUF
NEXT MEMBUF
NEXT CHAN
COUNT = COUNT - 1
No
COUNT = 0 ?
Yes
RESTORE: B, C, H, L
RETURN

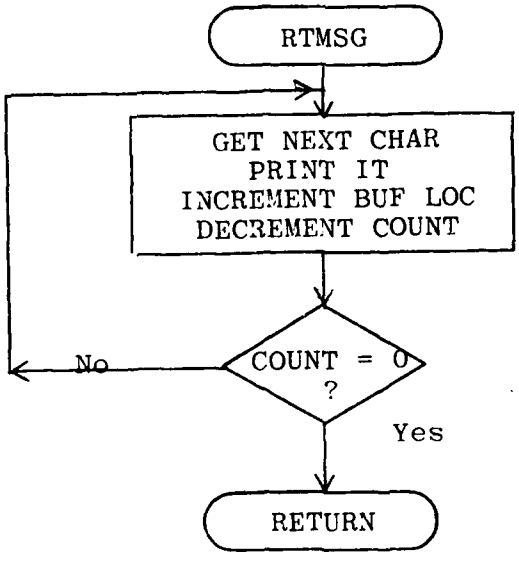


NOTES: PROM holds headers beginning at TEXL (3680H)
RAM holds binary data beginning at BINL (190H)
They are put into a character buffer, DIGL (302H)



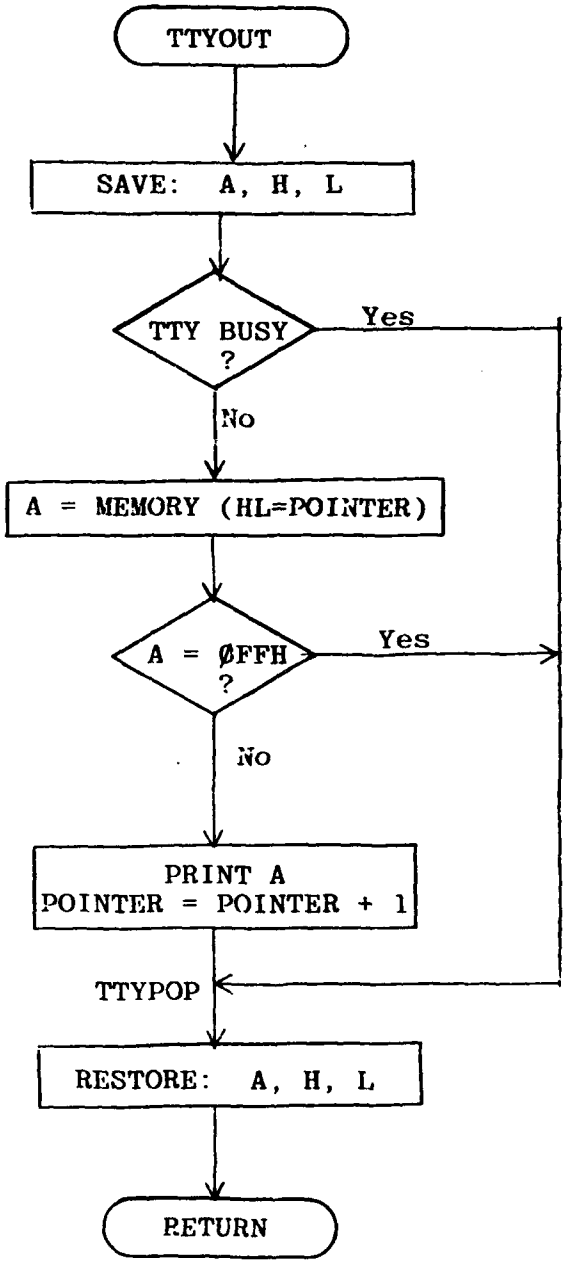
Notes:

Digl = 302H
Point = 300H

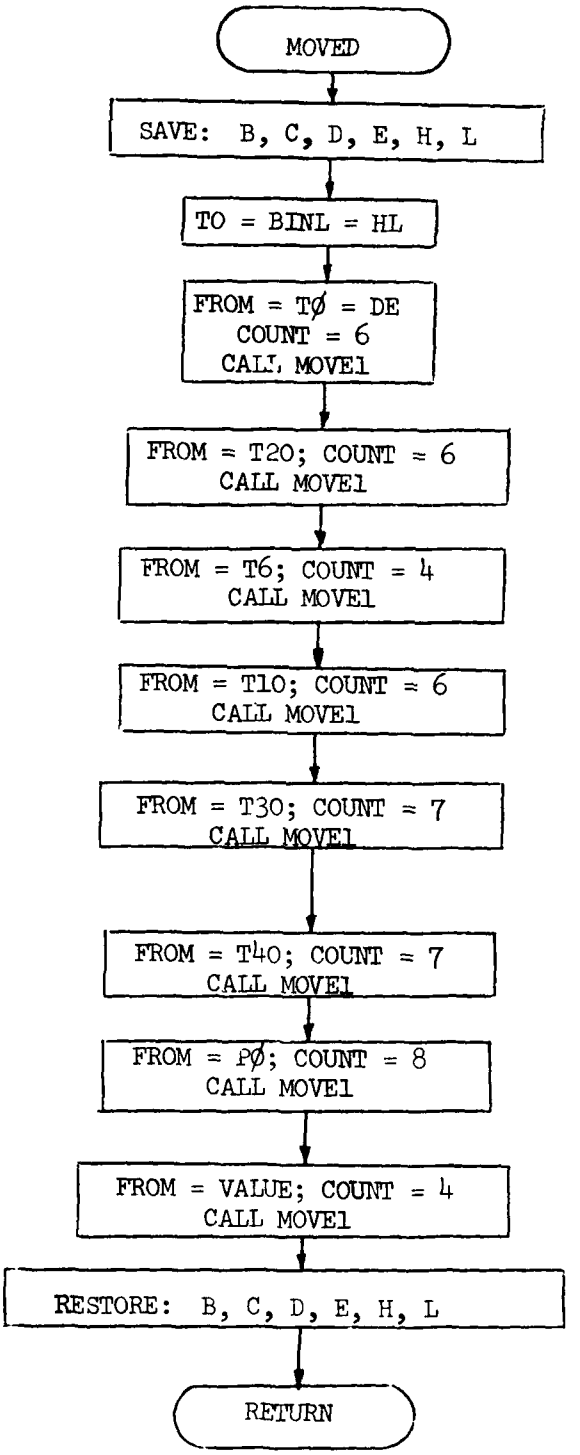


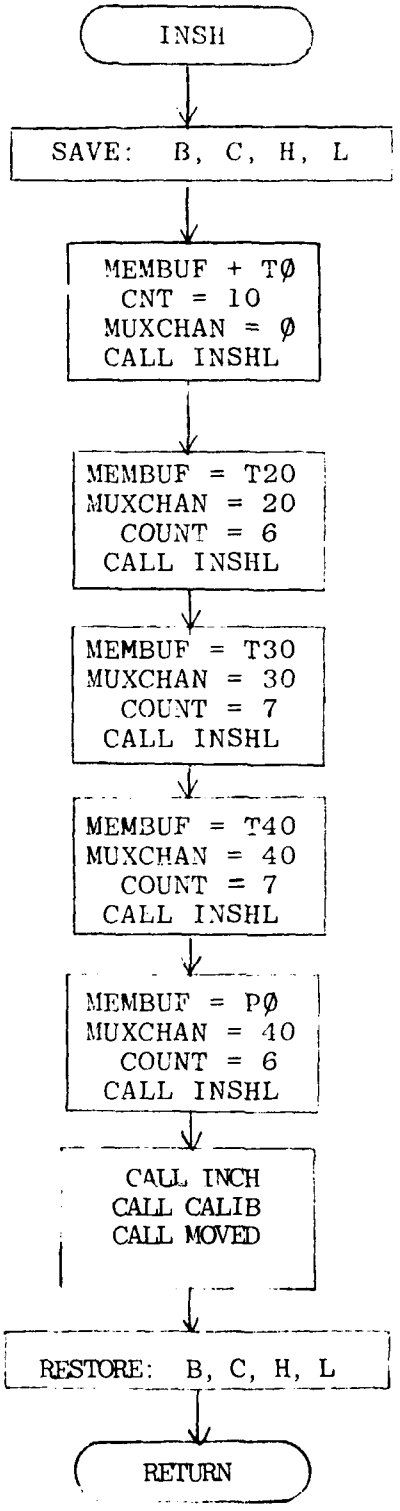
Notes:

HL = BUFLOC
C = Count
A destroyed

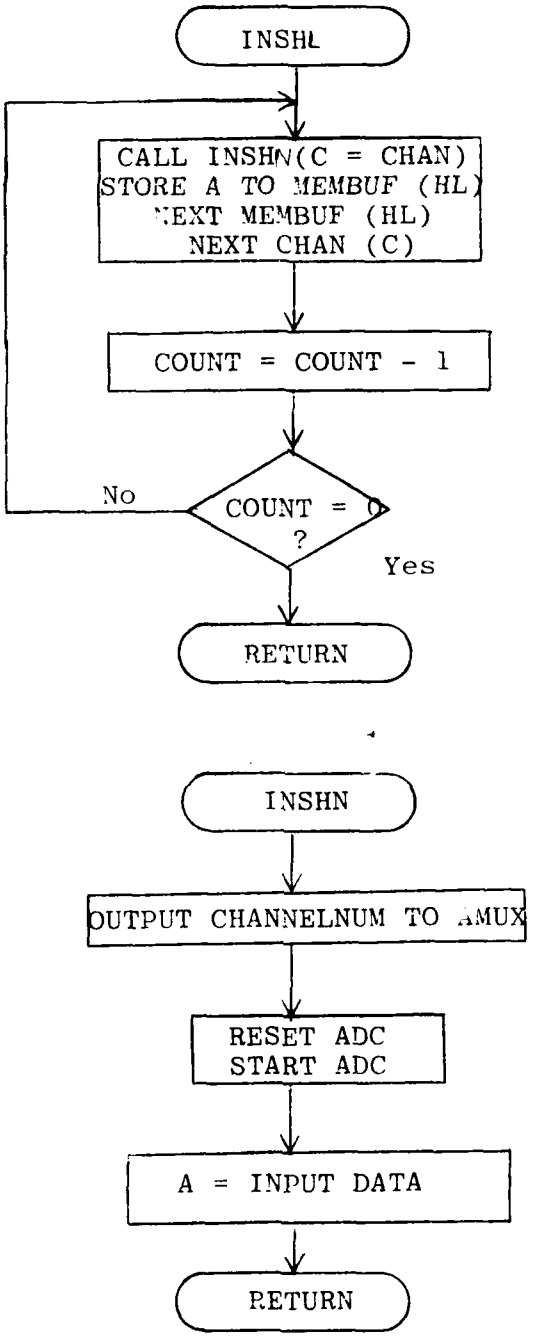


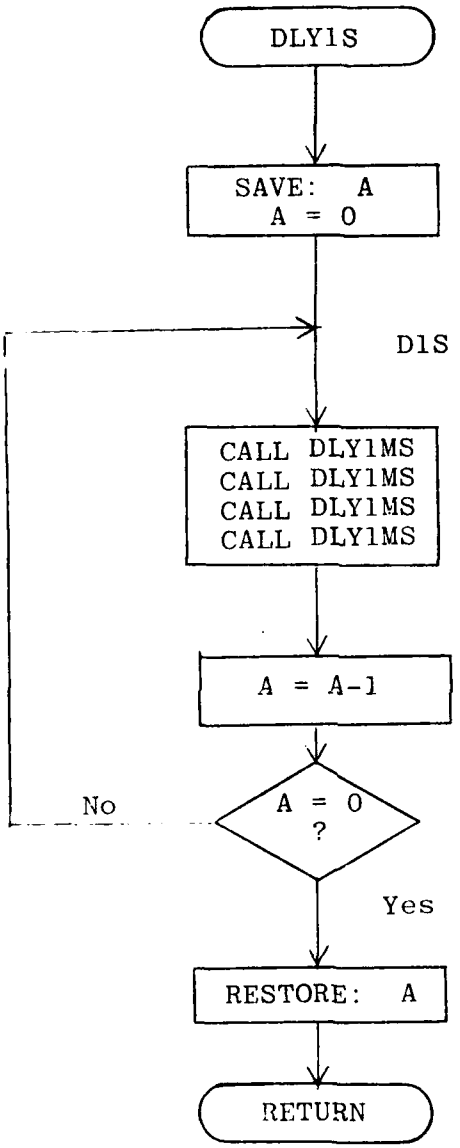
Notes: Pointer = 3ØØH
Prints to TTY, if possible

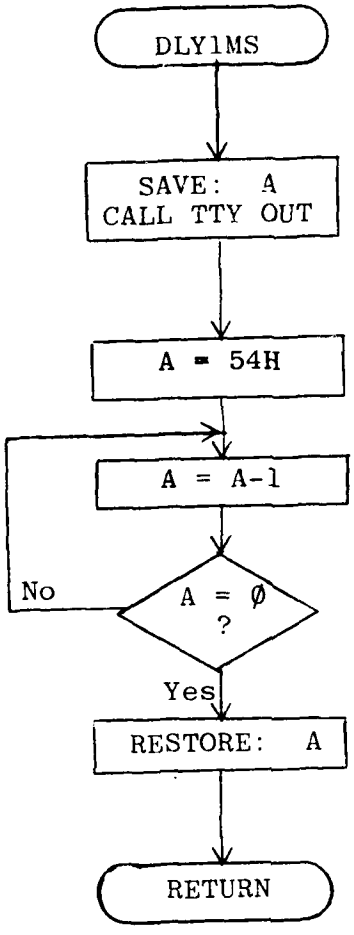

MOVED
SAVE: B, C, D, E, H, L
TO = BINL = HL
FROM = TØ = DE
COUNT = 6
CALL MOVE1
FROM = T20; COUNT = 6
CALL MOVE1
FROM = T6; COUNT = 4
CALL MOVE1
FROM = T10; COUNT = 6
CALL MOVE1
FROM = T30; COUNT = 7
CALL MOVE1
FROM = T40; COUNT = 7
CALL MOVE1
FROM = PØ; COUNT = 8
CALL MOVE1
FROM = VALUE; COUNT = 4
CALL MOVE1
RESTORE: B, C, D, E, H, L
RETURN



B = #BYTES
C = 1st channel on Amux
HL = MEMBUF


INSHL
CALL INSHN(C = CHAN)
STORE A TO MEMBUF (HL)
NEXT MEMBUF (HL)
NEXT CHAN (C)
COUNT = COUNT - 1
No
COUNT = 0
?
Yes
RETURN
INSHN
OUTPUT CHANNELNUM TO AMUX
RESET ADC
START ADC
A = INPUT DATA
RETURN


DLY1S
SAVE: A
A = 0
D1S
CALL DLY1MS
CALL DLY1MS
CALL DLY1MS
CALL DLY1MS
A = A-1
A = 0
?
No
Yes
RESTORE: A
RETURN



Notes: Delays 1 millisecond
Does TTY output, if needed

PRECEDING PAGE BLANK-NOT FILMED

APPENDIX E

TEST AND EVALUATION COMPUTER PROGRAMS

TITLE	PAGE NO.
Solar Test House Data Converter (paper tape to magnetic tape)	E-2
Load Analysis Program	E-6
Predict Solar Radiation	E-19

```
!JOB      SOLAR,ANALYSIS        .... MAKE TAPE
!PAU SYC
!RADEDIT
:DELETE (FILE,FP,SOLARTAP)
:SQUEEZ E FP
:ALLOT (FILE,FP,SOLARTAP),(RSIZE,30),(FORE,B),(FSIZE,200)
!JOB
!FORTRAN NS,SI,GO,S


C* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C* * * *      SOLAR HOUSE DATA CONVERTER (PAPER TO MAG TAPE)   * * * * * *
C* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C* * * *      WRITTEN IN XDS EXTENDED FORTRAN IV FOR THE DFEE SIGMA-5 * * *
C* * * *  BY CAPT ROY SCHMIESING, USAFA/DFEE, PH: (303) 472-2023 * * * * *
C* * * *      JAN, 1976,  PROPERTY OF THE U.S. GOV'T.   * * * * * * * * *
C* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *


      INTEGER OLDSIZ/293/,NEWSIZ/307/,COLON/Z3A/,BUF(1000),BUF1(2)
      LOGICAL   SSW
      REWIND 7
      IF(SSW(1)) OUTPUT 'FIX SSW & HIT RETURN';  INPUT(5) JUNK

      OUTPUT ' **** SOLAR HOUSE DATA CONVERTER ****'
    OUTPUT ' LIFT SENSE SWITCH 1 TO KILL JOB'
      OUTPUT 'SET MAG TAPE TO 200 BPI '
      OUTPUT 'ENTER 1234 IF YOU ARE STARTING WITH A NEW TAPE'
      OUTPUT ' ELSE, JUST HIT RETURN'
      INPUT (5) KEY
      IF(KEY.EQ.-999)OUTPUT 'LAST K?'; INPUT(5   ) K; GOTO 1313
    IF(KEY.EQ.1234) OUTPUT 'ALL OLD DATA WILL BE LOST. KILL IF NOK'
      IF(KEY.EQ.1234) GOTO 1

C---  SCAN TO EOF
      OUTPUT 'PASSING OLD DATA, K BLOCKS'
    K=0
10      READ(7,100,END=1313)
        READ(7,100,END=1314)
        K=K+1
        GOTO 10

1313    CONTINUE
        REWIND  7
        READ(7,11),(REC,I=1,K*2 )
11      FORMAT (A1)
        OUTPUT K
```

```
1         CONTINUE
          OUTPUT  ' TIME TAPE#'

C----     SCAN FOR INITIAL SYNC CHAR: "COLON"
 >>       CALL READ1(IN)
          IF(IN.NE.COLON)GOTO 99


C---- READ UNTIL NEXT COLON (BUT NO MORE THAN 1000 POINTS)
98        DO 600 I=2,1000
97        CALL READ1(IN)
          IF(IN.GE.128) IN=IN-128
      IF(SSW(4)) PRINT 133,IN
          IF(IN.EQ.0)GOTO 97
          BUF(I)=IN
          IF(IN.EQ.COLON) GOTO 999
600       CONTINUE

C---- IF FALLS THROUGH ,  MUST BE SOME PROBLRM
          OUTPUT ' REC TOO LONG'
          GOTO 1

C----     A COMPLETE DATA SET, COLON-TO-COLON, IS NOW IN. CHECK SIZE AS ERROR CK
999       CONTINUE
          IF(I.EQ.309)I=NEWSIZ
          IF(I.EQ.308)I=NEWSIZ
          IF(I.LT.7)GOTO 99
          K=K+1
          IF(I.NE.OLDSIZ.AND.I.NE.NEWSIZ)
     &  PRINT 876, (BUF(N),N=2,5),K,I;K=K-1;  GOTO 98
876       FORMAT( 1X,2Z1,1H:,2Z1,I5,'  ***DROPPED',I4)
          PRINT 123,  (BUF(N),N=2,5),K
123       FORMAT(       1X,2Z1,':',2Z1,I5)


          IF(I.EQ.NEWSIZ) CALL TWRITE
          IF(I.EQ.OLDSIZ)WRITE(7,777)
     *(BUF(I),I=002,005),(BUF(I),I=016,018),(BUF(I),I=020,022),
     *(BUF(I),I=024,026),(BUF(I),I=028,030),(BUF(I),I=032,034),
     *(BUF(I),I=036,038),(BUF(I),I=052,054),(BUF(I),I=056,058),
     *(BUF(I),I=060,062),(BUF(I),I=064,066),(BUF(I),I=068,070),
     *(BUF(I),I=072,074),(BUF(I),I=086,088),(BUF(I),I=090,092),
     *(BUF(I),I=094,096),(BUF(I),I=098,100),(BUF(I),I=102,104),
     *(BUF(I),I=106,108),(BUF(I),I=110,112),(BUF(I),I=114,116),
     *(BUF(I),I=118,120),(BUF(I),I=122,124),(BUF(I),I=136,138),
     *(BUF(I),I=140,142),(BUF(I),I=144,146),(BUF(I),I=148,150),
     *(BUF(I),I=152,154),(BUF(I),I=156,158),(BUF(I),I=160,162),
     *(BUF(I),I=172,174),(BUF(I),I=176,178),(BUF(I),I=180,182),
     *(BUF(I),I=184,186),(BUF(I),I=188,190),
     *(BUF(I),I=192,194),(BUF(I),I=196,198),(BUF(I),I=210,212),
     *(BUF(I),I=214,216),(BUF(I),I=218,220),(BUF(I),I=222,224),
     *(BUF(I),I=226,228),(BUF(I),I=230,232),(BUF(I),I=242,244),
     *(BUF(I),I=246,248),(BUF(I),I=250,252),(BUF(I),I=254,256)
```

```
777       FORMAT(  4Z1,31(1X,3Z1),/, 32(1X,3Z1))

          IF(SSW(3))
     X    PRINT 133,(I,BUF(I) ,BUF(I),I= 1,307)
133       FORMAT(I4,1X,Z2,4X,Z1)

          GOTO 98

1314      OUTPUT 'ODD # RECORDS. POSSIBLE BAD TAPE'; STOP
100       FORMAT(20Z3)


          SUBROUTINE TWRITE
          INTEGER CHAR(200) ,MAXC/142/

C----     KEEP ONLY LAST DIGIT OF ASCII NUMBERS AS NEW EBCDIC CHACTERS
          ENCODE(MAXC*4,666,CHAR,LAST)
     *(BUF(I),I=002,005),(BUF(I),I=016,018),(BUF(I),I=020,022),
     *(BUF(I),I=024,026),(BUF(I),I=028,030),(BUF(I),I=032,034),
     *(BUF(I),I=044,046),(BUF(I),I=060,062),(BUF(I),I=064,066),
     *(BUF(I),I=068,070),(BUF(I),I=072,074),(BUF(I),I=076,078),
     *(BUF(I),I=086,088),(BUF(I),I=102,104),(BUF(I),I=106,108),
     *(BUF(I),I=110,112),(BUF(I),I=114,116),(BUF(I),I=118,120),
     *(BUF(I),I=122,124),(BUF(I),I=126,128),(BUF(I),I=130,132),
     *(BUF(I),I=134,136),(BUF(I),I=138,140),(BUF(I),I=152,154),
     *(BUF(I),I=156,158),(BUF(I),I=160,162),(BUF(I),I=164,166),
     *(BUF(I),I=168,170),(BUF(I),I=172,174),(BUF(I),I=176,178),
     *(BUF(I),I=188,190),(BUF(I),I=192,194),(BUF(I),I=196,198),
     *(BUF(I),I=200,202),(BUF(I),I=204,206),(BUF(I),I=208,210),
     *(BUF(I),I=212,214),(BUF(I),I=222,224),(BUF(I),I=226,228),
     *(BUF(I),I=230,232),(BUF(I),I=242,244),(BUF(I),I=246,248),
     *(BUF(I),I=250,252),(BUF(I),I=258,260),(BUF(I),I=262,264),
     *(BUF(I),I=266,268),(BUF(I),I=270,272)
7777      FORMAT(4A1,31(1X,3A1),/,32(1X,3A1))

666       FORMAT(300(Z1,3X))

C----     SEE IF ANY NON-NUMERICS WERE READ FROM PAPER TAPE
          DO 100    I=1,MAXC
100       IF(NTEST(CHAR(I)).LT.0) GOTO 13

C----     IF NOT, SAVE ON MAG TAPE
          WRITE(7,7777),(CHAR(I),I=1,MAXC)
C----- CHECK FOR TIME DISCONTINUEITIES
          ENCODE(4,102,BUF1),(CHAR(I),I=1,4)
102       FORMAT(4A1)
          DECODE (4,103,BUF1) NOW
          DIF=NOW-OLD
103       FORMAT(I4)
          IF(DIF.GT.75.OR.DIF.LT.0)PRINT 104, OLD,NOW
104       FORMAT(' **** TIME JUMP:',I5,' TO',I5)
          OLD=NOW
          RETURN
```

```
C----     DUMP BAD RECORD
13        INERR=I
          OUTPUT ' ','REPORT TAPE ERROR TO CAPT SCHMIESING',INERR
         K=K-1
          PRINT 1300,(CHAR(I),I=1,MAXC)
1300      FORMAT('  *ERR: ', 4A1,31(1X,3A1),/,32(1X,3A1))
          RETURN

          END

          FUNCTION NTEST(IN)
          INTEGER NUM(11)/1H ,1H1,1H2,1H3,1H4,1H5,1H6,1H7,1H8,1H9,1H0/

          NTEST=-99
          DO 100 I=1,11
100       IF(IN.EQ.NUM(I)) GOTO 200
          RETURN

200       NTEST=I-1
          RETURN
          END
          SUBROUTINE READ1(NN)
       LOGICAL SSW
      IF(SSW(1))ENDFILE(7); REWIND(7); OUTPUT ' EOF'; CALL RLSFPOV
          CALL      RDTTY
S         ST#,7     IN
          NN=IN
       IF(SSW(4)) OUTPUT NN
          RETURN
          END
!MACRSYM GD,SI,NS
          DEF       RDTTY
          DEF       BUFFER
TTY       EQU       1
HSPTR     EQU       5
*  ONLY LAST CARD OF THE NEXT TWO WILL BE USED.
*            (THAT'S HOW WE SELECT WHICH PAPER
*             TAPE READER WE WANT TO USE).
DEVICE    SET       HSPTR (HIGH SPEED PAPER TAPE READER).
DEVICE    SET       TTY       TELETYPE (LOW SPEED).
RDTTY     RES       0
          L#,6      0
RETRY     LI,0      DA(COMD#)
          SIO,0     DEVICE
WAIT      TIO,0     DEVICE
          BCS,12    WAIT
          L#,0      6
          LB,7      BUFFER
          B         *15
          BOUND     8
COMD#     GEN,6,24  X'82',BA(BUFFER)
          DATA      1
BUFFER    RES       20
          END
!PAUSE . INTERRUPT & KEY-IN "SYC"
!LOAD GO,(FORE,1000),(UDCB,2),(LIB,USER,SYSTEM),(TEMP,500),(FILE,FP,SOLARTAP)
:ASSIGN (F:7,TYA01),(RECL,240)
:ASSIGN (F:5,TYA01),VFC
!MES YOU INTERRUPT AND KEYIN "RUN SOLARTAP"
!FIN
```

```
!JOB       SOLAR,PLT                .... ANALYZE/PLOT DATA ....
!RUN BP,SOLARPLT
3975,4082,
5,
132,
2,
4,
5,6,7,80,
4,
11,12,7,82,
GROUND ARRAY
ROOF ARRAY
!FIN
!JOB    SOLAR,PLOT                .... LOAD ANALYSIS PROGRAM ....
!FORTRAN S1,NS,GO


C* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C* * * *     SOLAR HOUSE DATA REDUCTION & PLOTTING                  * * * * *
C* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C* * * *     CAPT ROY SCHMIESING, USAFA/DFEE, PH: (303) 472-2023    * * * * *
C* * * *     CAPT J MIKE DAVIS USAFA/DFCEM PH: (303) 472-2649       * * * * *
C* * * *     WRITTEN IN ANSI FORTRAN IV FOR THE DFEE SIGMA 5        * * * * *
C* * * *     JAN, 1976,  PROPERTY OF THE U.S. GOV'T.                * * * * *
C* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *


      INTEGER SYM,MAXV(6),TDATA(99),LVAR(6,6),TITLE(10),PDATA(6,345,6)
C--   DEFINE FILES
          INTEGER DTAPE/8/,PTAPE/7/,USER/5/
C     MAGNETIC TAPE FORMAT:  EACH DATA BLOCK CONTAINS 64 SENSOR READINGS,
C     BEGINNING WITH THE TIME-OF-DAY AS SENSOR NUMB ONE. EACH BLOCK IS
C     RECORDED AS TWO TAPE RECORDS, ACCORDING TO FORMAT(14,31(13,1X,),/,3214).
C     THE TAPE IS 200 BPI, 7-TRACK,  128 CHARACTER RECORDS, BCL, EVEN PARITY.

C     THIS PROGRAM USES A CALCOMP 570 PLOTTER AND DFEE LIBRARY DRIVERS
          INTEGER OLDTIM,TIM1,TIM2,TIM3,TIM4
          DATA MUX/ 2400/,OLDT/9999.0/,LASTR/0/
          REWIND DTAPE
          K=0
```

```
C*****  INITIAL OPERATOR DIALOG    ***********************************************
          OUTPUT '  **** SOLAR DATA PLOTTER  ****'
          OUTPUT '   MOUNT DATA TAPE, 200 BPI'
1000      CONTINUE

1         OUTPUT ' ENTER MIN,MAX TAPE RECORD NUMBERS'
          INPUT(USER)  MINT, MAXT
          IF( MAXT-MINT .GE.350)OUTPUT 'SORRY, MAX IS 350';  GOTO 1

          OUTPUT ' ENTER NUMBER OF MONTH IN WHICH DATA WAS TAKEN'
          INPUT(USER)MO
          MONTH=MO
          IF(MO.LT.0)MONTH=-MO
          OUTPUT 'JULIEN DATE ? '
          INPUT(USER) DAY

C---- SKIP TO START OF DATA
          IF(MINT-LASTR.LT.2 ) GO TO 11
          DO 10 I=2,MINT-LASTR
          READ(DTAPE,70,END=1313)JUNK
10        READ(DTAPE,70,END=1313)JUNK
11        CONTINUE

2         CONTINUE
          IF(KEYR.EQ.1HR) GOTO 107
          OUTPUT 'HOW MANY PLOTS OF THIS DATA?'
          INPUT (USER  ) MAXP
          IF(MAXP.GT.6) OUTPUT 'SORRY, MAX IS 6'; GOTO 2

C---- READ IN VARIABLES TO BE PRINTED
          DO 106 NPLOT=1,MAXP
4         PRINT 104,NPLOT
104       FORMAT(' HOW MANY VARIABLES ON PLOT',I3)
          INPUT( USER ) MAXV(NPLOT)
          IF(MAXV(NPLOT).GT.6) OUTPUT 'SORRY, MAX IS 6';  GOTO 4

          PRINT 105, MAXV(NPLOT),NPLOT
105       FORMAT(' ENTER THE' I2,' VARIABLES OF PLOT',I2)
106       INPUT(USER),(LVAR(NPLOT,NVAR),NVAR=1,MAXV(NPLOT))
107       CONTINUE
          OUTPUT ' '
```

```
C*****  GET DATA FROM DATA TAPE  ***************************************************
          DO 100 IXT=1,MAXT-MINT+1
          READ(DTAPE,70,END=1313),(TDATA(I),I=1,64)
          IF(IXT.EQ.1) CALL INIT
          CALL      CALC
70        FORMAT(3214)

C---  FOR EACH PLOT
          DO 100 NPLOT=1,MAXP
C--- FOR ALL DATA ON THE PLOT
          DO 100 IXV=1,MAXV(NPLOT)
          IX=TDATA(1)
          IY=TDATA(LVAR(NPLOT,IXV))
          PDATA(NPLOT,IXT,IXV)=IY*MUX+IX
100       CONTINUE

C------- PLOT   -----
          OUTPUT ' '
          LASTR = MAXT
          OUTPUT ' PLEASE MOUNT PLOT TAPE AT 200 BPI'
          READ(108 ,81)KEYR
81        FORMAT(A1)
          IF(KEYR. EQ. 1HR) GO TO 1000
          REWIND DTAPE
          IF(KEYR.NE.1H )STOP

C----- LOOP FOR EACH PLOT REQUESTED
          DO 300 NPLOT=1,MAXP



C*****  LABEL PLOTS  ***************************************************************
C---- C----INITIALIZE
      CALL CLRPLT(NPLOT)
          PRINT 41, NPLOT
41        FORMAT(' TITLE FOR PLOT',I2,'?')
          READ(USER,40) TITLE
40        FORMAT(10A4)
      CALL SYMBOL (3.0,0.8,0.4,0.0,1,0,17,'USAFA SOLAR HOUSE')
C     X,Y,SIZE, ANGLE, N, (MODE, LEN, STRING)
C
C     H-AXIS
          CALL AXIS(1.5,2.0,'TIME OF DAY',-11,12.0,0.0,0.0,2.0,0)
C     ARGUMENTS: XPAG, YPAG, IBCD, NCHAR, SIZE, ANGLE, YMIN
C
C     V-AXIS
          CALL AXIS(1.5,2.0,TITLE,40  ,8.0,90.0,0.0,32.0,-1)
C     PEN TO ORIGIN
C     ARGUMENTS:  X0, DX, Y0, DY
          CALL OFFSET(-3.0,2.0,-64.,32.0)
          CALL PLOT(0.0,0.0,-21)
```

```
C*****  MAKE DATA PLOTS  ************************************************************
C----  LOOP FOR EACH TRACE ON THIS PLOT
          DO 501 IXV=1,MAXV(NPLOT)

C----  LOOP FOR ALL THE TIME-POINTS ON THIS TRACE
          PRINT 430,NPLOT,LVAR(NPLOT,IXV)
430       FORMAT(' PLOT',213)
          DO 500 IXT=1,MAXT-MINT+1
          SYM=0
          IF(MOD(IXT,20).EQ.1) SYM=2*IXV+4
          X=MOD(PDATA(NPLOT,IXT,IXV),MUX)
          X=INT(X/100)+AMOD(X,100.0)/60.0
          Y=PDATA(NPLOT,IXT,IXV)/MUX
C---- PLOT SYMBOL (RAISE PEN IF GOING BACK IN TIME)
          IF(OLDT.GT.X)SYM=SYM+1
          OLDT=X
C                                 WILD POINT EDIT
                                  IF((IABS(X2-X).LT.45).AND.
     +                               (IABS(X2-X1).GT.100))
     +                            X=X-MOD(0,2)+1
                                  X2=X1
                                  X1=X

          IF (X.LT.0.) X = 0.
          IF (X.GE.24.) X = 24.
          IF (Y.LT.0.) Y = 0.
          IF (Y.GE.256.) Y = 255.
          CALL PLOT(X,Y,-SYM)
500       CONTINUE
          OLDT=99999.
501       CONTINUE

C---- TERMINATE THIS PLOT
          CALL PLOT(15.0,0.0,1)
300       CONTINUE

C---- TERMINATE ALL PLOTS
          CALL CLRPLT(999)
          STOP 30
1313      OUTPUT 'HIT EOF ON INPUT TAPE'
```

```
      SUBROUTINE CALC
      INTEGER C1,F1,F2
C---------- CALCULATE DERIVED QUANTITIES BASED ON MEASURED VALUES

C  ***************************************************************************$$$$
C    TO ANALYSE DATA PROPERLY YOU MUST KNOW IF IT IS IN OLD OR NEW FORMAT.
C    OLD FORMAT DATA WAS RECORDED PRIOR TO 1600 8 JAN 76.
C    TO PROPERLY ANALYSE OLD FORMAT DATA, THE NUMBER OF THE MONTH IN
C    WHICH THE DATA WAS TAKEN MUST BE PRECEEDED BY A NEGATIVE SIGN.
C    EXAMPLE FOR DECEMBER DATA: "-12," FOR MONTH CARD IN DATA DECK
C    FOR NEW FORMAT DATA, ENTER JUST THE CORRECT MONTH WITHOUT A NEGATIVE
C    SIGN.  EXAMPLE FOR FEBURARY DATA: "2," FOR MONTH CARD IN DATA DECK
C  ***************************************************************************$$$$
C         OLD FORMAT                    NEWFORMAT
C         C1 = IDATA(47)                C1 = IDATA(43)
C         F1 = IDATA(45)                F1 = IDATA(41)
C         F2 = IDATA(46)                F2 = IDATA(42)
C  ***************************************************************************$$$$
C  ***************************************************************************$$$$
      C1 = IDATA(43)
      F1 = IDATA(41)
      F2 = IDATA(42)
      IF(MO.GT.0) GOTO 650
C---- IF MONTH IS NEGATIVE, DATA IS IN OLD FORMAT, SO REDEFINE C1,F1,F2

      IF(IXT.EQ.1) OUTPUT 'ANALYSIS BASED ON OLD FORMAT'
      C1 = IDATA(47)
      F1 = IDATA(45)
      F2 = IDATA(46)
650   CONTINUE
C  ***************************************************************************$$$$
      IDATA(65) = IBIT(1,C1)
      IDATA(66) = IBIT(2,C1)
      IDATA(67) = IBIT(3,C1)
      IDATA(68) = IBIT(4,C1)
      IDATA(69) = IBIT(7,C1)
```

```
C       SUN
            N = IDATA(13)
            NEWTIM = IDATA(1)
            IF(IXT.EQ.1) ITIM = NEWTIM
            IF(N.LE.0) GO TO 1
            DELTIM = LMIN(NEWTIM,OLDTIM)

            SUN = (N/256.) * (716.49) * HA
            SUNGA = (N/256.) * (716.49) * RB(GATILT) * HA
            SUNRA = (N/256.) * (716.49) * RB(RATILT) * HA
            QSUN = SUN * (DELTIM/60.)
            QSUNGA = SUNGA * (DELTIM/60.)
            QSUNRA = SUNRA * (DELTIM/60.)
            QSUNT = QSUNT + QSUN
            QSNGAT = QSNGAT + QSUNGA
            QSNRAT = QSNRAT + QSUNRA

            IF(IXT.LT.MAXT-MINT+1) GO TO 30
            PRINT 701, QSUNT,SUMTIM,NEWTIM
701         FORMAT(' SUN BTU/SF HORIZ =',F8.0,'  (',I4,'-',I4,')')
            PRINT 706,QSNGAT
706         FORMAT(' SUN BTU/SF GA =',F8.0)
            PRINT 707,QSNRAT
707         FORMAT(' SUN BTU/SF RA =',F8.0)
30          CONTINUE

            IDATA(74) = SUN/6.
            IDATA(75) = QSUN
            IDATA(85) = QSUNGA
            IDATA(86) = QSUNRA + 144.
            IDATA(91) = SUNGA/6.
            IDATA(92) = SUNRA/6. + 144.
            IDATA(98) = IDATA(92) - 144.
            SUMTIM = SUMTIM + DELTIM *HA
            HA = 1.0
            OLDTIM = NEWTIM
            OLDN = N
            GO TO 3
1           IF(OLDN.LE.0) GO TO 2
            NEWTIM = IDATA(1)
            DELTIM = LMIN(NEWTIM,OLDTIM)
            SUN = (N/256.) * (716.49) * HA
            SUNGA = (N/256.) * (716.49) * RB(GATILT) * HA
            SUNRA = (N/256.) * (716.49) * RB(RATILT) * HA
            QSUN = SUN * (DELTIM/60.)
            QSUNGA = SUNGA * (DELTIM/60.)
            QSUNRA = SUNRA * (DELTIM/60.)
            QSUNT = QSUNT + QSUN
            QSNGAT = QSNGAT + QSUNGA
            QSNRAT = QSNRAT + QSUNRA
            IDATA(74) = SUN/6.
            IDATA(75) = QSUN
            IDATA(85) = QSUNGA
            IDATA(86) = QSUNRA + 144.
            IDATA(91) = SUNGA/6.
            IDATA(92) = SUNRA/6. + 144.
            IDATA(98) = IDATA(92) - 144.
            SUMTIM = SUMTIM + DELTIM
```

```
      PRINT 701, QSUNT,SUMTIM,NEWTIM
      PRINT 706,QSNGAT
      PRINT 707,QSNRAT

      HA = 0
      OLDN = 0
      OLDTIM = NEWTIM
      GO TO 3

2     TDATA(75) = 0
      TDATA(74) = 0
      TDATA(85) = 0
      TDATA(86) = 144.
      TDATA(91) = 0
      TDATA(92) = 144.
      TDATA(98) = TDATA(92) - 144
      OLDTIM = NEWTIM

3     CONTINUE

C     HEATCOIL


      NCNTRL = TDATA(68)
      IF(NCNTRL.LE.0) GO TO 4

      DTEMP = TDATA(20) - TDATA(21)
      NEWTIM = TDATA(1)
      DELTIM = AMIN(NEWTIM,TIM1)
      QHC = (FLOW)*(SPHEAT)*(DTEMP)*(DELTIM)*(CNTRL1)*(8.34)
      TDATA(76) = QHC/100.0
      QHCT = QHCT + QHC
      STIM = STIM + DELTIM* (CNTRL1)

      IF(IXT. EQ. MAXT - MINT + 1)
     &  PRINT 702,QHCT,STIM,NEWTIM
702   FORMAT(' HC BTU =',F8.0,'  (',I4,'-',I4,')')

      TIM1 = NEWTIM
      CNTRL1 = NCNTRL
      GO TO 6
4     IF(CNTRL1.LE.0) GO TO 5
      DTEMP = TDATA(20) -TDATA(21)
      NEWTIM = TDATA(1)
      DELTIM = AMIN(NEWTIM,TIM1)
      QHC = (FLOW)*(SPHEAT)*(DTEMP)*(DELTIM)* (8.34)
      TDATA(76) = QHC/100.0
      QHCT = QHCT + QHC
      STIM = STIM + DELTIM

      PRINT 702,QHCT,STIM,NEWTIM

      CNTRL1 = 0
      TIM1 = NEWTIM
      STIM = 0
      GO TO 6
5     TDATA(76) = 0
      TIM1 = NEWTIM
6     CONTINUE
```

```
C     GAS

      NCNTRL = IDATA(69)
      IF(NCNTRL. LE.0) GO TO 7
      NEWTIM = IDATA(1)
      DELTIM = LMIN(NEWTIM,TIM2)
      QG = GSFLOW * DELTIM * 795.0 * CNTRL2
      IDATA(77) = QG/100.0
      IDATA(78) = (IDATA(76) + IDATA(77))/10.
      QGT = QGT + QG
      GTIM = GTIM + DELTIM * CNTRL2

      IF(IXT. EQ. MAXT - MINT + 1)
     &  PRINT 700,QGT,GTIM,NEWTIM
700   FORMAT('  GAS BTU =',F8.0,'  (',I4,' AT ',I4,')')

      TIM2 = NEWTIM
      CNTRL2 = NCNTRL
      GO TO 9
7     IF(CNTRL2. LE. 0) GO TO 8
      NEWTIM = IDATA(1)
      DELTIM = LMIN(NEWTIM,TIM2)
      QG = GSFLOW * DELTIM * 795.0
      IDATA(77) = QG/100.0
      IDATA(78) = (IDATA(76) + IDATA(77))/10.
      GTIM = GTIM + DELTIM
      QGT = QGT + QG

      PRINT 700,QGT,GTIM,NEWTIM

      CNTRL2 = 0
      TIM2 = NEWTIM
      GTIM = 0
      GO TO 9
8     IDATA(77) = 0
      IDATA(78) = (IDATA(76) + IDATA(77))/10.
      TIM2 = NEWTIM
9     CONTINUE


C     GROUND ARRAY


      NCNTRL = IDATA(66)
      IF(NCNTRL. LE. 0) GO TO 10

      TTB = IDATA(7)
      IF(CNTRL3. LE. 0) PRINT 710,TTB,NEWTIM
710   FORMAT('  TANK WATER TEMP AT BEGIN OF GA OPERATION =',
     &  I4,' AT ',I5)
```

```
      DTEMP = TDATA(5) - TDATA(6)
      FLO = F1
      GFLOW=EVAL(FLO)
      TDATA(80) = GFLOW
      NEWTIM = TDATA(1)
      DELTIM = LMIN(NEWTIM,TIM3)
      GATIM = GATIM + DELTIM * CNTRL3
      QGA = GFLOW * SPHT * DTEMP * DELTIM * 8.83 * CNTRL3
      TDATA(79) = QGA/221.521
      TDATA(87) = QGA/100.
      TDATA(93) = (TDATA(79)*10.)/DELTIM
      TDATA(96) = (TDATA(93)/TDATA(91))*100.
      QGAT = QGAT + QGA

      IF(IXT.EQ.MAXT-MINT+1)
     &  PRINT 703,QGAT,GATIM,NEWTIM
703   FORMAT('  GA BTU =',F8.0,'  (',I4,' AT ',I4,')')

      TIM3 = NEWTIM
      CNTRL3 = NCNTRL
      GO TO 12
10    IF(CNTRL3.LE.0) GO TO 11

      TTE = TDATA(7)
      PRINT 711,TTE,NEWTIM
711   FORMAT('  TANK WATER TEMP AT END OF GA OPERATION =',
     &  I4,' AT ',I5)

      DTEMP = TDATA(5) - TDATA(6)
      FLO = F1
      GFLOW=EVAL(FLO)
      TDATA(80) = GFLOW
      NEWTIM = TDATA(1)
      DELTIM = LMIN(NEWTIM,TIM3)
      GATIM = GATIM + DELTIM
      QGA = GFLOW * SPHT * DTEMP * DELTIM * 8.83
      TDATA(79) = QGA/221.521
      TDATA(87) = QGA/100.
      TDATA(93) = (TDATA(79)*10.)/DELTIM
      TDATA(96) = (TDATA(93)/TDATA(91))*100.

      QGAT = QGAT + QGA
      PRINT 703,QGAT,GATIM,NEWTIM

      CNTRL3 = 0
      TIM3 = NEWTIM
      GATIM = 0
      GO TO 12
11    TDATA(79) = 0
      TDATA(80) = 0
      TDATA(87) = 0
      TDATA(93) = 0
      TDATA(96) = (TDATA(93)/TDATA(91))*100.
      TIM3 = NEWTIM
12    CONTINUE
```

```
C       ROOF ARRAY

        NCNTRL = TDATA(67)
        IF(NCNTRL. LE. 0) GO TO 13

        TTB = TDATA(7)
        IF(CNTRL4. LE. 0) PRINT 712,TTB,NEWTIM
712     FORMAT('  TANK WATER TEMP AT BEGIN OF RA OPERATION =',
     &  I4,' AT ',I5)
        DTEMP = TDATA(11) - TDATA(12)

        FLO = F2
        RFLOW=EVAL(FLO)
        TDATA(82) = RFLOW
        NEWTIM = TDATA(1)
        DELTIM = LMIN(NEWTIM,TIM4)
        RATIM = RATIM + DELTIM * CNTRL4
        QRA = RFLOW * SPHT * DTEMP * DELTIM * CNTRL4 * 8.83
        TDATA(81) = QRA/221.521
        TDATA(83) = TDATA(79) + TDATA(81)
        TDATA(88) = QRA/100.
        TDATA(89) = TDATA(87) + TDATA(88) + 50.
        TDATA(90) = TDATA(81) + 144.
        TDATA(94) = (TDATA(81)*10.)/DELTIM + 144.
        TDATA(95) = TDATA(94) - 144.
        TDATA(97) = (TDATA(95)/TDATA(98)) * 100. + 100.
        QRAT = QRAT + QRA

        IF(IXT.EQ.MAXT-MINT+1)
     &  PRINT 704,QRAT,RATIM,NEWTIM
704     FORMAT('  RA BTU =',F8.0,'  (',I4,' AT ',I4,')')

        TIM4 = NEWTIM
        CNTRL4 = NCNTRL
        GO TO 15
13      IF(CNTRL4. LE. 0) GO TO 14

        TTE = TDATA(7)
        PRINT 713,TTE,NEWTIM
713     FORMAT('  TANK WATER TEMP AT END OF RA OPERATION =',
     &  I4,' AT ',I5)
        DTEMP = TDATA(11) - TDATA(12)
        FLO = F2
        RFLOW=EVAL(FLO)
        TDATA(82) = RFLOW
        NEWTIM = TDATA(1)
        DELTIM = LMIN(NEWTIM,TIM4)
        RATIM = RATIM + DELTIM
        QRA = RFLOW * SPHT * DTEMP * DELTIM * 8.83
        TDATA(81) = QRA/221.521
        TDATA(83) = TDATA(79) + TDATA(81)
        TDATA(88) = QRA/100.
        TDATA(89) = TDATA(87) + TDATA(88) + 50.
        TDATA(90) = TDATA(81) + 144.
        TDATA(94) = (TDATA(81)*10.)/DELTIM + 144.
        TDATA(95) = TDATA(94) - 144.
        TDATA(97) = (TDATA(95)/TDATA(98)) * 100. + 100.
        QRAT = QRAT + QRA
        PRINT 704,QRAT,RATIM,NEWTIM
```

```
          TIM4 = NEWTIM
          CNTRL4 = 0
          RATIM = 0
          GO TO 15
14        TDATA(81) = 0
          TDATA(82) = 0
          TDATA(83) = TDATA(79) + TDATA(81)
          TDATA(88) = 0
          TDATA(89) = TDATA(87) + TDATA(88) + 50.
          TDATA(90) = 144.
          TDATA(94) = 144.
          TDATA(95) = 0
          TDATA(97) = (TDATA(95)/TDATA(98)) * 100. + 100.
          TIM4 = NEWTIM

15        CONTINUE

          TDATA(65) = 200.0 + 8* TDATA(65)
          TDATA(66) = 224.0 + 8.0 * TDATA(66)
          TDATA(67) = 248.0 + 8.0 * TDATA(67)
          TDATA(68) = 208.0 + 8.0 * TDATA(68)

          TDATA(69) = 232.0 + 8.0 * TDATA(69)

          IF(IAT. NE. MAXT-MINT+1) RETURN
          OUTPUT ' '
          TBTU = QHCT + QGT
          SH = QHCT/TBTU * 100.
          TENGA = QSNGAT * 221.521
          TENRA = QSNRAT * 221.521
          GACE = QGAT/TENGA * 100.
          RACE = QRAT/TENRA * 100.
          PRINT 82,INT(DAY),ITIM,NEWTIM
82      FORMAT(/,' *** SUMMARY OF DAY',I4,'   (',I4,' TO ',I4,')  ***')
          PRINT 715,TBTU,QHCT,SH
          PRINT 716,TENGA,QGAT,GACE
          PRINT 717,TENRA,QRAT,RACE
715   FORMAT('  HOUSE BTU''S:   GAS+SOLAR=',F8.0,'       SOLAR=',F8.0,
     &      '  %SOLAR=',F5.1)
716   FORMAT(' GROUND BTU''S:   AVAILABLE=',F8.0,'   COLLECTED=',F8.0,
     &      '  % EFF =',F5.1)
717   FORMAT('  ROOF  BTU''S:   AVAILABLE=',F8.0,'   COLLECTED=',F8.0,
     &    '  % EFF =',F5.1)
          RETURN
```

```
      SUBROUTINE INIT
      DO 1 I=64,99
1     TDATA(I)=0
      OLDN = 0
      SUMTIM = 0
      QSUNT = 0
      HA = 0
      OLDTIM = TDATA(1)
      SPHEAT = 1.0
      FLOW = 11.88
      CNTRL1 = 0
      QHCT = 0
      TIM1 = TDATA(1)
      STIM = 0
      TIM2 = TDATA(1)
      GSFLOW = 2.069
      CNTRL2 = 0
      QGT = 0
      GTIM = 0
      SPHT =.775
      GATIM = 0
      RATIM = 0
      QGAT = 0
      QRAT = 0
      TIM3 = TDATA(1)
      TIM4 = TDATA(1)
      CNTRL3 = 0
      CNTRL4 = 0
      QSNGAT = 0
      QSNRAT = 0
      X = 3.1416/180.0
      GATILT = 45. * X
      RATILT = 52. * X
      RETURN


      FUNCTION RB(TILT)
C     THIS FUNCTION CALCULATES CORRECTION FACTOR FOR RAD ON TILTED
C     SURFACE
      AT = 39. * X
      DEC = (X * 23.45) * SIN((284.+ DAY)*(360./365.) * X)
      HOD = LMIN(NEWTIM,0)/60.0 + EQNT(MONTH)
      HANGLE =(15.0 * (12.0 - HOD) * X)
      COST = COS( AT-TILT)*COS(DEC)*COS(HANGLE) + SIN( AT-TILT)
     &  *SIN(DEC)
      COSZ  = COS( AT)*COS(DEC)*COS(HANGLE) + SIN( AT)*SIN(DEC)
      RB = COST/COSZ
      RETURN
      END
```

```
      FUNCTION LMIN(T2,T1)
C---- THIS FUNCTION COMPUTES THE LENGTH IN MINUTES BETWEEN T1 AND T2
      INTEGER T1,T2
      IF(T1.GT.T2) OUTPUT 'ERROR IN LMIN', T1,T2,OLDTIM,TIM1,TIM2,
     &  TIM3,TIM4
      LMIN=(T2/100-T1/100)*60+MOD(T2,100)-MOD(T1,100)
      RETURN
      END
      FUNCTION IBIT(IN,INC)
      IBIT= (INC/2**(IN))-(INC/2**(IN   +1))*2
      RETURN
      END


      FUNCTION EVAL(VALVE)
C--   EVALUATE FLOW RATE FROM CALIBRATION DATA BASED ON VALVE POSN
      DATA MAXTAB/30/
      REAL TABLE (2, 30)/0.0,0.0,32.,0.0,60.,2.05,64.,2.12,
     &  70.,2.47,80.,2.76,90.,3.11,100.,3.39,110.,3.68,120.,4.10,
     &  130.,4.38,140.,4.67,150.,5.23,160.,7.07,164.,8.09,
     &  170.,9.62,180.,11.59,189.,13.01,199.,13.86,204.,14.71,
     &  209.,14.99,214.,15.13,224.,15.55,237.,15.84,
     &  245.,16.12,253.,16.40,255.,16.69/

C-- SCAN TABLE FOR LINES TO INTERPOLATE BETWEEN
      DO 10 ITAB=1,MAXTAB
10    IF(TABLE(1,ITAB).GE.VALVE) GOTO 99

C---  IF LARGER THAN MAX, FALL THROUGH
      OUTPUT 'VALVE OUT OF RANGE', VALVE
      EVAL=16.69
      RETURN

99    CONTINUE
      DVALVE=TABLE(1,ITAB)-TABLE(1,ITAB-1)
      DFLO  =TABLE(2,ITAB)-TABLE(2,ITAB-1)
      EVAL=TABLE(2,ITAB-1)+ DVALVE/(TABLE(1,ITAB)-TABLE(1,ITAB-1))
     +  * DFLO
      RETURN
      END


      FUNCTION EQNT (MONTH)
C     THIS FUNCTION EVALUATES THE EQN OF TIME FOR MID MONTH
      REAL ANS (12) /-9.,-13.5,-9.,-1.,3.5,-1.,-5.,-3.,5.,13.,
     &  13.,4./
      EQNT = ANS(MONTH) / 60.0
      RETURN
      END
!PAU KEYIN "SYC"
!OLOAD GO,(UDC8,3),(LIB,USER,SYSTEM),(FILE,BP,SOLARPLT)
:ASSIGN (F:7,7TA81)
:ASSIGN (F:8,7TA81)
:ASSIGN (F:5,CRA03)
!MES RUN THIS PROGRAM WITH A "RUN BP,SOLARPLT" DECK
!FIN
```

```
C     ****************************************************************
C     *                                                              *
C     *  SOLRAD/NBSLD PROGRAM ADAPTED TO B6700/7700 COMPUTER         *
C     *  SUBROUTINE SUN FROM NBSLD HEAT TRANSFER SUBROUTINES, GRAPH  *
C     *  PACKAGE FROM CAST LIBRARY, USAFA B6700.  THIS PROJECT FOR   *
C     *  CE 499, SOLAR ENERGY RESEARCH.                              *
C     *    ADAPTED BY C1C JAMES P. HUNT,  STUDENT, CE 499.           *
C     *       CADET SQUADRON 19, PHONE: 472-4741                     *
C     *                                                              *
C     ****************************************************************

C*****************************************************************************
C***NBSLD SUBROUTINE SUN ACCEPTS JULIAN DAY AND TILT OF SURFACE
C***CONSIDERED TO COMPUTE SOLAR RADIATION INTENSITIES, INCLUDING DIRECT,
C***DIFFUSE, AND TOTAL RADIATION.
C*****************************************************************************

      SUBROUTINE SUN (A,B,C,D,E,F,G,H,I)
      REAL LAT,LATD,LONG,MERID,LOND

      REAL      A0(5)/.302,-.0002,368.44,.1717,0.0905/,A1(5)/-22.93,.419
     X7,24.52,-.0344,-.0410/,A2(5)/-.229,-3.2265,-1.14,.0032,.0073/,A3(5
     X)/-.243,-.0903,-1.09,.0024,.0015/,B1(5)/3.851,-7.351,.58,-.0043,-.
     X0034/,B2(5)/.002,-9.3912,-.18,0.,0.0004 /,B3(5)/-.055,-.3361,.28,-
     X.0008,-.0006/

      COMMON /SOL/ LAT,LONG,TZN,WAZ,WT,CN,DST,LPYR,S(35)

C     S(1)= LATITUDE,DEGREES(+NORTH,-SOUTH)
C     S(2)= LONGITUDE,DEGREES(+WEST,-EAST)
C     S(3)= TIME ZONE NUMBER
C                STANDARD TIME          DAYLIGHT SAVING TIME
C       ATLANTIC        4                        3
C       EASTERN         5                        4
C       CENTRAL         6                        5
C       MOUNTAIN        7                        6
C       PACIFIC         8                        7
C     S(4)= DAYS (FROM START OF YEAR)
C     S(5)= TIME (HOURS AFTER MIDNIGHT, 24 HOUR CLOCK)
C     S(6)= DAYLIGHT SAVING TIME INDICATOR (1=DST)
C     S(7)= GROUND REFLECTIVITY
C     S(8)= CLEARNESS NUMBER
C     S(9)= WALL AZIMUTH ANGLE (DEGREES FROM DUE SOUTH)
C     S(10)= WALL TILT ANGLE (DEGREES FROM HORIZONTAL)
C     S(11)= SUNRISE TIME
C     S(12)= SUNSET TIME
C     S(13)= COS(Z)     DIRECTION COSINE
C     S(14)= COS(N)     DIRECTION COSINE
C     S(15)= COS(S)     DIRECTION COSINE
C     S(16)= ALPHA      DIRECTION COSINE NORMAL TO TILITED SURFACE
C     S(17)= BETA       DIRECTION COSINE NORMAL TO TILITED SURFACE
C     S(18)= GAMMA      DIRECTION COSINE NORMAL TO TILITED SURFACE
C     S(19)= COS(ETA) COSINE OF INCIDENCE ANGLE
C     S(20)= SOLAR ALTITUDE ANGLE
C     S(21)= SOLAR AZIMUTH ANGLE
```

```
C     S(22)= DIFFUSE SKY RADIATION ON A HORIZONTAL SURFACE
C     S(23)= DIFFUSE GROUND REFLECTED RADIATION
C     S(24)= DIRECT NORMAL RADIATION
C     S(25)= TOTAL SOLAR RADIATION INTENSITY
C     S(26)= DIFFUSE SKY RADIATION INTENSITY
C     S(27)= GROUND REFLECTED DIFFUSE RADIATION INTENSITY
C     S(28)= SUN DECLINATION ANGLE (DEGREES,+SUMMER,-WINTER)
C     S(29)= EQUATION OF TIME (HOURS)
C     S(30)= APPARENT SOLAR CONSTANT
C     S(31)= ATMOSPHERIC EXTINCTION COEFFICIENT
C     S(32)= SKY DIFFUSE FACTOR
C     S(33)= CLOUD COVER MODIFIER
C     S(34)= INTENSITY OF DIRECT SOLAR RADIATION ON SURFACE
C     S(35)= HOUR ANGLE (DEGREES)
C     S(36)=TOTAL INTENSITY ON SURFACE, BTU/FT**2-HR


      S(4)=A
      S(5)=B
      S(10)=C

C  ********************************************************************
C     THESE VARIABLES ARE CONSTANT FOR LOCATION OF USAFA, MOUNTAIN STAN-
C     DARD TIME.
      S(1)=38.75; S(2)=104.75; S(3)=7; S(7)=.2; S(8)=1.00
      S(33)=1.0
C  ********************************************************************
      S(34)=0; S(26)=0; S(27)=0; S(25)=0

      PI=3.1415927

C     FIND VALUES OF EQUATION OF TIME, SOLAR COSTANT, ATMOSPHERIC EXTINCTION
C     COEFFICIENT AND SKY DIFFUSE FACTOR
      X=2*PI/366.*S(4)
      C1=COS(X)
      C2=COS(2*X)
      C3=COS(3*X)
      S1=SIN(X)
      S2=SIN(2*X)
      S3=SIN(3*X)
      DO 10 K=1,5
      KS=(K-1)+28
10    S(KS)=A0(K)+A1(K)*C1+A2(K)*C2+A3(K)*C3+B1(K)*S1+B2(K)*S2+B3(K)*S3

      S(29)= S(29)/60
      LATD=S(1)

      LONG=S(2)
      MERID=15*S(3)
      LOND=LONG-MERID

      Y=S(28)*PI/180
      YY=LATD*PI/180
      HP=-TAN(Y)*TAN(YY)
      TR=12./PI*ARCOS(HP)
```

```
      S(11)=(12-TR)-S(29)+LOND/15
      S(12)=24.-S(11)

      D=S(11)
      E=S(12)

      H=15*(S(5)-12+S(3)+S(29)-S(6))-S(2)
      S(35)=H
      S(13)=SIN(YY)*SIN(Y)+COS(YY)*COS(Y)*COS(H*PI/180)
      HP1=180.*ARCOS(HP)/PI
      X1=ABS(HP1)
      X2=ABS(H)
      IF (X1-X2)  130,20,20

20    S(14)=COS(Y)*SIN(H*PI/180.)
      S(15)= SQRT(1.-S(13)*S(13)-S(14)*S(14))

      STEST=S(15)
      STEST1=COS(H*PI/180.)-TAN(Y)/TAN(YY)
      IF  (STEST1)  40,30,30
30    S(15)=STEST
      GO TO 50

40    S(15)=-STEST

50    S(20)=ARSIN(S(13))
      GO TO 80

70    S(21)=PI-ARSIN(S(14))/COS(S(20))
80    S(20)=180.*S(20)/PI
      S(21)=180.*S(21)/PI
      S(24)=S(30)*S(8)*S(33)*EXP(-S(31)/S(13))
      S(22)=S(32)*S(24)/S(8)**2
      S(23)=S(7)*(S(22)+S(24)*S(13))

      WY=S(10)*PI/180.
      S(16)=COS(WY)
      WA=S(9)*PI/180.
      S(16)=COS(WY)
      S(17)=SIN(WA)*SIN(WY)
      S(18)=COS(WA)*SIN(WY)

      S(19)=S(16)*S(13)+S(17)*S(14)+S(18)*S(15)

      S(34)=S(24)*S(19)

      Y=0.45
      IF  (S(19)+0.2)  100,100,90

90    Y=0.55+0.437*S(19)+0.313*S(19)**2
100   IF  (S(19))  110,110,120

110   S(19)=0.
      S(34)=0.
```

```
120   CONTINUE
      S(26)=S(22)*Y
      S(27)=S(23)*(1-S(16))/2.
      S(25)=S(34)+S(26)+S(27)
      GO TO 150

130   DO 140 J=14,27
140   S(J)=0
      S(34)=0

150   CONTINUE
      F=S(25)
      G=S(26)
      H=S(27)
      I=S(34)
      RETURN
      END
C     ******************************************************************
C     *                                                                *
C     *  SOLRAD/NBSLD: THIS IS THE ACTUAL PROGRAM WHICH CALLS          *
C     *  SUBROUTINE SUN FROM ASHRAE AND SUBROUTINE PLOT FROM           *
C     *  LIBRARY FILE.                                                 *
C     *                                                                *
C     ******************************************************************

      EXTERNAL PLOT
      DIMENSION S(36), X(100), Y(100)
      READER=5


600   READ (5,5)S(4),S(10)
5     FORMAT (I3,2X,I3)

C****INSERT DATA CARDS AFTER "BIND=FROM SOL/" CONTROL CARD WITH <I> DATA
C****PRECEDING THE DATA DARDS.  DATA FORMAT: 3 DIGIT DAY, 2 SPACES,
C****3 DIGIT TILT ANGLE, BOTH DATA RIGHT PREFERRED. TO TERMINATE,
C****ADD FINAL DATA CARD: DAY=367, TILT=0009

      IF (367-S(4)) 500,500,10
10    PRINT 11,S(4),S(10)
11    FORMAT ('1DAY= ',I3,4X,'TILT= ',I2,' FROM HORIZONTAL (DEGREES)'/)
      PRINT 15
15    FORMAT (20X,'ALL VALUES FOR SURFACE TILT ABOVE, IN BTU/HR.-FT**2'
     X,//' HOUR',7X,'DIRECT',6X,'SKY DIFFUSE',3X,'GRND. REFL.',6X,'TOTAL
     X',7X,'TOTAL(BTU/MIN)',/)

      I=0
```

```
C***TOTSUN EQUALS RADIATION TOTAL FOR GIVEN DAY*******
      TOTSUN=0

      DO 200  R=0,24,.25
      S(5)=R
      I=I+1

      CALL SUN (S(4),S(5),S(10),S(11),S(12),S(25),S(26),S(27),S(34))
      TOTSUN=.25*S(25)+TOTSUN
      X(I)=R
      Y(I)=S(25)
      S(36)=S(25)/60.
200   PRINT 300,S(5),S(34),S(26),S(27),S(25), S(36)
300   FORMAT (F6.2,5(5X,F9.3))

      S(34)=0; S(26)=0; S(27)=0; S(25)=0; S(36)=0

      PRINT 23,S(11),S(12),TOTSUN
23    FORMAT (/,' SUNRISE AT ',F5.2,' HOURS',5X,' SUNSET AT ',F5.2,' HOU
     XRS',/,' TOTAL ENERGY FOR DAY: ',F9.2,' BTU/SQ. FT.')

C  SUBROUTINE PLOT CALL ALGOL PROCEDURE WHICH CALLS A B6700
C  LIBRARY ROUTINE TO GRAPH THE VALUES OF SOLAR RADIATION.

      CALL PLOT (X,Y,S(4),S(10))
      GO TO 600
500   STOP
      END
 DATA
 COMPILE SOL/PLOT ALGOL LIBRARY
PROGRAM
PROCEDURE PLOT(X,Y,Z,W); REAL ARRAY X¢*1, Y¢*1; INTEGER Z,W;
    BEGIN
       FILE LINE (KIND=PRINTER);
$ INCLUDE "*CAST/GRAPHPAC."
     FORMAT TITLE (X40,"TOTAL SOLAR RADIATION ON SURFACE",/);
     FORMAT LABE (/,X20,"RADIATION (BTU/SQ. FT./ HOUR) VS. TIME");
     FORMAT DATE (X30,"PLOT FOR DAY  ",I3,/,X30,"TILT= ",I3," DEGREES");
     SGRAPHER (TITLE,LABE,X,Y,96,".");
     WRITE (LINE,DATE,Z,W);
END OF PLOT;
DATA
045  000
046  000
047  000
070  000
071  000
072  000
092  000
093  000
094  000
400  00
338  000
339  000
355  000
```

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APPENDIX F

SOLAR ENERGY SYSTEM TABULARIZED PERFORMANCE

DATA SUMMARY

(December 1975 to April 1976)

TITLE	PAGE NO.
December 1975	F-2
January 1976	F-8
February 1976	F-14
March 1976	F-20
April 1976	F-25

Date	Solar Insolation (BTU/SF/Day) Cum, Horizontal	Degree Days	Storage Tank Temp Daily		(45°) Ground Array Performance			(52°) Roof Array Performance			Remarks
			Start	Finish	BTU's Available	BTU's Collected	%	BTU's Available	BTU's Collected	%	
1 DEC	826	22	N/A	N/A	101,499	49,710	48.9	79,966	41,326	51.7	Pyranomet Out Data From Phoe House, COS
2 DEC	759	15	100°F	100°F	206,978	17,887	8.6	201,449	9,122	4.5	" "
3 DEC	830	23	102°F	102°F	246,338	110,556	44.9	241,695	131,225	54.3	" "
4 DEC	910	21	92°F	108°F	410,638	236,410	57.6	423,021	194,976	46.1	" "
5 DEC	782	25	105°F	112°F	748,083	166,534	22.3	800,269	132,019	16.5	" "
6 DEC	345	25	98°F	101°F	133,198 (E)	28,354	21.3	152,982	17,617	8.7	" "
7 DEC	645	20	99°F	98°F	249,035	57,974	23.3	286,009	12,628	4.4	" "
8 DEC	717	24	96°F	102°F	276,834	34,878	12.6	317,936	163,128	51.3	" "
9 DEC	870	19	97°F	103°F	307,238	201,258	65.5	352,854	47,684	13.5	" "
10 DEC	791	16	102°F	116°F	619,827	212,313	34.3	660,958	250,043	37.8	" "
11 DEC	810	25	106°F	106°F	312,741	29,409	9.4	359,175	32,403	9.0	" "
12 DEC	UK	38	UK	UK	UK	UK	N/A	UK	UK	N/A	" "
13 DEC	835	36	102°F	102°F	322,394	179,017	55.5	370,260	164,269	44.4	" "
14 DEC	760	33	101°F	106°F	386,966	206,754	53.4	402,214	256,772	63.8	Pyranometer Fixed
15 DEC	635	32	104°F	111°F	312,558	195,703	62.6	324,088	232,158	71.6	
21 DEC	205	30	UK	UK	104,450	0	0	108,558	0	0	
22 DEC	734	32	104°F	108°F	370,242	191,093	51.6	384,579	235,965	61.4	
23 DEC	497	33	60°F	90°F	252,855	79,397	31.4	262,794	50,584	19.2	Tank Sens Out
24 DEC	748	36	87°F	97°F	380,242	207,799	54.6	395,187	115,939	29.3	" "
25 DEC	348	33	94°F	94°F	197,786	32,330	16.3	205,988	24,980	12.1	" "
26 DEC	535	32	93°F	98°F	291,527	116,107	39.8	304,450	78,880	25.9	" "

Date	Solar Insolation (BTU/SF/Day) Cum, Horizontal	Degree Days	Storage Tank Temp Daily		(45°) Ground Array Performance			(52°) Roof Array Performance			Remarks
			Start	Finish	BTU's Available	BTU's Collected	%	BTU's Available	BTU's Collected	%	
27 DEC	779	33	92°F	101°F	397,907	203,712	51.2	413,678	189,433	45.8	Tank Sensor Fixed
28 DEC	326	43	98°F	97°F	164,238	0	0	170,577	0	0	
29 DEC	449	17	94°F	94°F	237,904	105,633	44.4	246,460	77,293	31.4	
30 DEC	630	29	92°F	100°F	337,202	162,100	48.1	351,744	179,195	50.9	
31 DEC	251	45	96°F	93°F	136,802	0	0	142,098	0	0	

Date	Solar Insolarion (BTU/SF/Day) Cum, Horizontal	Degree Days	House Heating Demand (BTU's)				Time Interval Analysis	Average Hourly Heating Demand BTU's/Hour
			Total	Solar	Gas	% Solar		
1 DEC	826	22 (43)*	400,480 129,509 529,989	0	529,989	0	0 to 0825 1055 to 2355 21 Hrs 25 Min 21.42 Hrs.	24,743
2 DEC	759	15 (50)	272,964 27,894 300,858	0	300,858	0	0 to 1015 1355 to 2355 20 Hrs 15 Min 20.75 Hrs	14,857
3 DEC	830	23 (42)	298,866 88,576 387,442	0	387,442	0	0 to 1330 1405 to 2355 20.33 Hrs	19,058
4 DEC	910	21 (44)	198,141	0	189,141	0	0 to 2355 23.92 Hrs	7,907
5 DEC	782	25 (40)	84,619	10,899	73,720	12.9	0 to 1530 15.50 Hrs	5,459
6 DEC	345	25 (40)	UK	UK	UK	N/A	1835 to 2355 11.33 Hrs	N/A
7 DEC	645	20 (45)	UK	UK	UK	N/A	0 to 1740 17.67 Hrs	N/A
8 DEC	717	24 (41)	23,909	0	23,909	0	0 to 1910 19.17 Hrs	1,247
9 DEC	870	19 (46)	143,456	0	143,456	0	0 to 2355 23.92 Hrs	5,997
10 DEC	721	16 (49)	45,826	0	45,826	0	0835 to 2355 15.5 Hrs	2,957

Date	Solar Insolarion (BTU/SF/Day) Cum, Horizontal	Degree Days	House Heating Demand (BTU's)				Time Interval Analysis	Average Hourly Heating Demand BTU's/Hour
			Total	Solar	Gas	% Solar		
11 DEC	810	25 (40)	207,591	40,226	167,365	19.4	0 to 1050 10.83 Hrs	19,168
15 DEC	UK	38 (27)	123,531	0	123,531	0	1845 to 2355 5.17 Hrs	23,984
16 DEC	835	36 (29)	656,679	150,599	506,080	22.8	0 to 1950 19.83 Hrs	33,115
19 DEC	760	33 (32)	689,905	50,332	639,573	7.3	0 to 2335 23.58 Hrs	29,258
20 DEC	635	32 (33)	333,063	86,001	247,062	25.8	0950 to 2355 14.08 Hrs	23,655
21 DEC	205	30 (35)	926,826	10,304	916,522	1.1	0 to 2355 23.92 Hrs	38,747
22 DEC	734	32 (33)	707,928	269,592	438,336	38.1	0 to 2355 23.92 Hrs	29,596
23 DEC	497	33 (32)	841,976	5,152	836,824	0.6	0 to 2355 23.92 Hrs	35,200
24 DEC	748	36 (29)	539,951	0	539,951	0	0 to 2355 23.92 Hrs	22,573
25 DEC	378	33 (32)	761,111	0	761,111	0	0 to 2355 23.92 Hrs	31,819
26 DEC	535	32 (33)	761,111	0	761,111	0	0 to 2355 23.92 Hrs	31,819

Date	Solar Insolarion (BTU/SF/Day) Cum, Horizontal	Degree Days	House Heating Demand (BTU's)				Time Interval Analysis	Average Hourly Heating Demand BTU's/Hour
			Total	Solar	Gas	% Solar		
27 DEC	779	33 (32)	681,414	0	681,414	0	0 to 2355 23.92 Hrs	28,487
28 DEC	326	43 (22)	1,071,930	0	1,071,930	0	0 to 2355 23.92 Hrs	44,813
29 DEC	449	17 (48)	567,845	0	567,845	0	0 to 2355 23.92 Hrs	23,739
30 DEC	630	29 (36)	73,720	0	73,720	0	UK (12 Assumed)	N/A
31 DEC	251	45 (20)	UK	UK	UK	N/A	0 to 1405 1415 to 2355 23.75 Hrs	N/A

* (N) - Average Daily Temperature = 65 - Degree Days

SOLAR TEST HOUSE

Summary of Data - December 1975

- Days of Record Considered - 22
- Total Hours from Analyzed - 456
- House Heating Demand (Hourly) - 10,526,290 Btu's (23,084 Btu's/Hr)
- Average Solar Insolation Available - 673 Btu's/SF
- Average Number of Degree Days - 28 (Therefore, average outside temperature = 37°F)
- Btu's Available to the Solar Arrays - 14,364,347 (136% of Heating Demand)
- Btu's Collected by the Solar Arrays and Storage Tank - 5,345,994 (51% of Heating Demand and 37% of that Available)
- Btu's Provided to the House for Heating by the Solar Energy System - 623,105
  - Based on 100% Furnace Efficiency - 6% of Heating Demand
  - Based on 70% Furnace Efficiency - 8% of Heating Demand
- Overall System Performance - 12% (Btu's Provided/Btu's Collected)

Date	Solar Insolation (BTU/SF/Day) Cum, Horizontal	Degree Days	Storage Tank Temp Daily		(45°) Ground Array Performance			(52°) Roof Array Performance			Remarks
			Start	Finish	BTU's Available	BTU's Collected	%	BTU's Available	BTU's Collected	%	
1 JAN	608	59	87°F	90°F	316,701	86,011	27.2	329,700	68,967	20.9	
2 JAN	397	54	84°F	84°F	206,269	29,788	14.4	214,698	44,993	21.0	
3 JAN	612	54	89°F	89°F	409,212	106,129	25.9	425,022	111,799	26.3	
4 JAN	674	39	91°F	130°F	330,573	68,633	20.8	342,678	77,218	22.5	
5 JAN	75	26	UK	UK	40,462	0	0	42,228	0	0	
8 JAN	743	38	UK	103°F	373,278	66,651	17.9	387,619	58,993	15.2	
11 JAN	779	32	105°F	105°F	376,368	49,491	13.1	389,671	51,147	13.1	
12 JAN	763	30	99°F	104°F	368,000	130,811	35.5	380,958	77,171	20.3	
13 JAN	857	41	92°F	101°F	412,842	207,001	50.1	427,364	115,115	26.9	
14 JAN	465	39	102°F	103°F	221,168	134,247	60.7	228,713	88,899	38.9	
15 JAN	481	22	96°F	96°F	238,112	14,545	6.1	246,990	10,428	4.2	
16 JAN	753	26	94°F	104°F	352,042	188,343	53.5	363,573	144,210	39.7	
20 JAN	114	37	108°F	108°F	64,083	25,096	39.2	67,070	23,262	34.7	
21 JAN		34	UK	98°F	UK	UK	N/A	UK	UK	N/A	
22 JAN	229	23	94°F	94°F	114,740	-183,020	-159	119,212	17,455	14.7	Ground Array Pumped Heat Away!
23 JAN	929	26	94°F	94°F	436,252	125,141	28.7	449,797	173,441	38.6	
24 JAN	545	36	101°F	102°F	240,782	23,851	9.9	247,505	25,531	10.3	
25 JAN	516	50	99°F	98°F	222,219	10,312	4.6	227,949	2,564	1.1	
26 JAN	954	52	96°F	98°F	431,816	96,061	22.2	444,801	45,135	10.1	
27 JAN	845	35	96°F	103°F	372,791	102,307	27.7	383,171	159,107	45.5	
28 JAN	893	30	100°F	106°F	395,898	84,256	21.3	407,119	85,953	21.1	

Date	Solar Insolation (BTU/SF/Day) Cum, Horizontal	Degree Days	Storage Tank Temp Daily		(45°) Ground Array Performance			(52°) Roof Array Performance			Remarks
			Start	Finish	BTU's Available	BTU's Collected	%	BTU's Available	BTU's Collected	%	
29 JAN	987	25	102°F	106°F	434,968	137,257	31.6	447,048	190,131	42.5	
30 JAN	885	29	102°F	105°F	373,976	112,358	30.0	382,986	135,780	35.5	
31 JAN	457	7	101°F	UK	196,102	-252	-	201,078	0	0	Pumped Heat Away from Ground Array

Date	Solar Insolarion (BTU/SF/Day) Cum, Horizontal	Degree Days	House Heating Demand (BTU's)				Time Interval Analysis	Average Hourly Heating Demand BTU's/Hour
			Total	Solar	Gas	% Solar		
1 JAN	608	59 (6)*	UK	UK	UK	N/A	0 to 1130 1245 to 2355 22.67 Hrs	N/A
2 JAN	397	54 (11)	UK	UK	UK	N/A	0 to 1200 1950 to 2355 16.08 Hrs	N/A
3 JAN	812	54 (11)	UK	UK	UK	N/A	0 to 2355 23.92 Hrs	N/A
4 JAN	674	39 (26)	90,014	26,256	63,758	29.2	0 to 2355 23.92 Hrs	3,763
5 JAN	75	26 (39)	UK	UK	UK	N/A	0 to 1008 1715 to 1930	N/A
8 JAN	743	38 (27)	UK	UK	UK	N/A	0745 to 1549 8.07 Hrs	N/A
11 JAN	779	32 (33)	177,159	103,438	73,721	58.4	0816 to 2350 15.57 Hrs	11,378
12 JAN	763	30 (35)	448,008	71,436	376,572	15.9	0 to 1810 18.17 Hrs	24,656
13 JAN	857	41 (24)	800,582	69,355	731,227	8.7	0 to 2350 23.83 Hrs	33,596
14 JAN	465	39 (26)	320,461	113,247	207,214	35.3	1150 to 2351 12.01 Hrs	26,705

Date	Solar Insolarion (BTU/SF/Day) Cum, Horizontal	Degree Days	House Heating Demand (BTU's)				Time Interval Analysis	Average Hourly Heating Demand BTU's/Hour
			Total	Solar	Gas	% Solar		
15 JAN	481	22 (43)	601,717	0	601,717	0	0 to 2350 23.83 Hrs	25,250
16 JAN	753	26 (39)	470,216	0	470,216	0	0 to 2350 23.83 Hrs	19,732
20 JAN	114	37 (28)	177,574	64,005	113,569	36.0	1430 to 2354 9.4 Hrs	18,891
21 JAN		34 (31)	510,066	0	510,066	0	0 to 0752 1715 to 2350 14.45 Hrs	35,299
22 JAN	229	23 (42)	420,405	0	420,405	0	0 to 1030 10.5 Hrs	40,039
23 JAN	929	26 (39)	166,419	0	166,419	0	0745 to 1530 1545 to 2350 15.83 Hrs	10,513
24 JAN	545	36	810,924	0	810,924	0	0 to 2355 23.92 Hrs	33,902
25 JAN	516	50 (15)	814,909	0	814,909	0	0 to 0508 10 to 2358 19.1 Hrs	42,665
26 JAN	954	52 (13)	1,117,759	0	1,117,759	0	0 to 2355 23.92 Hrs	46,729
27 JAN	845	35 (30)	486,157	0	486,157	0	0 to 0400 0730 to 2345 20.25 Hrs	24,008

Date	Solar Insolarion (BTU/SF/Day) Cum, Horizontal	Degree Days	House Heating Demand (BTU's)				Time Interval Analysis	Average Hourly Heating Demand BTU's/Hour
			Total	Solar	Gas	% Solar		
28 JAN	893	30 (35)	493,731	17,536	476,194	3.6	0 to 2345 23.75 Hrs	20,789
29 JAN	987	25 (40)	491,755	87,289	404,466	43.5	0 to 0647 0715 to 2349 23.35 Hrs	21,060
30 JAN	885	29 (36)	674,146	90,360	583,786	13.4	0 to 2345 23.75 Hrs	28,385
31 JAN	457	7 (58)	559,877	0	559,877	0	0 to 1200 12.0 Hrs	46,656

* (N)--Average Daily Temperature = 65 - Degree Days

SOLAR TEST HOUSE

Summary of Data - January 1976

- Days of Record Considered	- 18
- Total Hours from Above Analyzed	- 361
- House Heating Demand (Hourly)	- 9,361,879 Btu's (26,681 Btu's/Hour)
- Average Solar Insolation Available	- 674 Btu's/SF
- Average Number of Degree Days	- 33 (Therefore average outside temperature = 32°F)
- Btu's Available to the Solar Arrays	- 11,340,325 (118% of Heating Demand)
- Btu's Collected by the Solar Arrays and Storage Tank	- 2,933,157 (30% of Heating Demand and 26% of that Available)
- Btu's Provided to the House for Heating by the Solar Energy System	- 642,923
Based on 100% Furnace Efficiency	- 7% of Heating Demand
Based on 70% Furnace Efficiency	- 9% of Heating Demand
- Overall System Performance	- 22% (Btu's Provided/Btu's Collected)

Date	Solar Insolation (BTU/SF/Day) Cum, Horizontal	Degree Days	Storage Tank Temp Daily		(45°) Ground Array Performance			(52°) Roof Array Performance			Remarks
			Start	Finish	BTU's Available	BTU's Collected	%	BTU's Available	BTU's Collected	%	
3 FEB	N/A	27	N/A	N/A	N/A	N/A	N/A	N/A	N/A		Data does not cover period of time when sun was out.
4 FEB	383	48	98°F	98°F	159,366	0	0	162,969	0	0	
5 FEB	489	52	94°F	94°F	198,775	13,643	6.9	202,858	7,403	3.6	
6 FEB	830	45	90°F	97°F	345,241	97,651	28.3	353,040	123,568	35.0	
7 FEB	1073	30	95°F	103°F	440,105	158,553	36.0	449,490	144,930	32.2	
8 FEB	685	17	101°F	101°F	290,351	14,398	5.0	297,435	23,402	7.9	
9 FEB	808	14	96°F	101°F	324,261	113,179	34.9	330,512	144,504	43.7	
10 FEB	1000	26	100°F	100°F	410,947	124,574	30.3	419,768	146,187	43.3	
11 FEB	1189	28	100°F	107°F	483,856	200,325	41.4	493,826	216,744	43.9	
12 FEB	810	18	100°F	110°F	317,568	217,258	68.4	322,944	157,163	48.7	Ground Array Recharged
13 FEB	1095	22	92°F	115°F	430,092	310,064	72.1	437,481	319,954	73.2	Roof Array Recharged
14 FEB	1042	25	101°F	120°F	399,245	266,760	66.8	405,136	316,706	78.2	
15 FEB	731	25	107°F	110°F	280,203	85,333	30.5	284,350	90,532	31.8	
16 FEB	1231	27	97°F	112°F	475,547	345,853	72.7	482,717	297,063	61.5	
17 FEB	907	33	100°F	106°F	341,745	142,701	41.8	346,226	126,992	36.7	
18 FEB	1169	27	90°F	105°F	438,651	308,669	70.4	444,215	253,124	57.0	
19 FEB	1236	25	99°F	113°F	460,565	325,099	70.6	466,074	276,428	59.3	
20 FEB	333	40	94°F	92°F	120,423	0	N/A	121,480	0	N/A	
21 FEB	Partial = 67	47	90°F	101°F	31,084	18,193	58.5	32,083	1,434	4.5	
22 FEB	1335	29	94°F	113°F	486,188	382,138	78.6	490,846	256,890	52.3	
23 FEB	1112	20	91°F	104°F	409,570	230,770	56.3	413,981	184,385	44.5	

Date	Solar Insolation (BTU/SF/Day) Cum, Horizontal	Degree Days	Storage Tank Temp Daily		Ground Array Performance			Roof Array Performance			Remarks
			Start	Finish	BTU's Available	BTU's Collected	%	BTU's Available	BTU's Collected	%	
24 FEB	1145	25	100°F	112°F	401,887	289,191	72.0	404,188	235,824	58.3	
25 FEB	1170	25	93°F	107°F	421,169	286,239	67.9	425,031	248,246	58.4	
26 FEB	1194	21	99°F	110°F	423,088	299,741	70.8	425,893	236,334	55.5	
27 FEB	670	22	102°F	102°F	233,896	46,165	19.7	235,058	26,493	11.3	
28 FEB	1044	22	100°F	111°F	350,657	282,223	80.5	350,909	232,120	66.1	
29 FEB	1335	26	103°F	114°F	455,340	300,575	66.0	456,452	239,571	52.5	

Date	Solar Insolarion (BTU/SF/Day) Cum. Horizontal	Degree Days	House Heating Demand (BTU's)				Time Interval Analysis	Average Hourly Heating Demand BTU's/Hour
			Total	Solar	Gas	% Solar		
3 FEB	N/A	27	158,681	21,203	137,478	13.4	1645 to 2348 7.1 Hrs	22,349
4 FEB	393	48	1,239,293	0	1,239,293	0	0 to 2355 23.92 Hrs	51,810
5 FEB	489	52	1,063,965	0	1,063,965	0	0 to 1421 1800 to 2348 20.15 Hrs	52,802
6 FEB	830	45	990,244	0	990,244	0	0 to 2348 23.8 Hrs	41,607
7 FEB	1073	30	649,536	0	649,536	0	0 to 2354 23.9 Hrs	27,177
8 FEB	685	17	484,164	0	484,164	0	0 to 2347 23.78 Hrs	20,360
9 FEB	808	14	288,904	0	288,904	0	0 to 0842 0900 to 1345 1600 to 2345 21.2 Hrs	13,627
10 FEB	1000	26	407,220	24,671	382,549	6.1	0 to 2345 23.75 Hrs	17,146
11 FEB	1189	28	628,261	46,468	581,793	7.1	0 to 2355 23.92 Hrs	24,328
12 FEB	810	18	65,788	65,788	0	100.0	0920 to 1315 1445 to 2345 12.92 Hrs	5,093
13 FEB	1095	29	269,792	269,792	0	100.0	0 to 0930 1000 to 2345 23.25 Hrs	11,604

Date	Solar Insolarion (BTU/SF/Day) Cum, Horizontal	Degree Days	House Heating Demand (BTU's)				Time Interval Analysis	Average Hourly Heating Demand BTU's/Hour
			Total	Solar	Gas	% Solar		
14 FEB	1042	25	210,359	98,782	111,577	47.0 0 to 0700 10.1 Hrs, 0912 to 2345 81.6 Hrs	0 to 0700 0912 to 2345 21.55 Hrs	9,761
15 FEB	731	35	187,651	115,923	71,728	61.8	0 to 2348 23.80 Hrs	7,885
16 FEB	1237	27	452,996	106,312	410,788	9.3 0 to 1911 10.9 Hrs 1930 to 2346 100.0 Hrs	0 to 1911 1930 to 2346 23.45 Hrs	19,320
17 FEB	907	33	577,108	200,536	376,572	34.7	0 to 2345 23.75 Hrs	24,299
18 FEB	1169	27	578,464	80,353	498,111	13.9	0 to 2345 23.75 Hrs	24,356
19 FEB	1236	25	541,878	139,404	402,474	25.7	0 to 2345 23.75 Hrs	22,816
20 FEB	333	40	937,296	154,266	783,030	16.5	0 to 2346 23.75 Hrs	39,465
21 FEB	Partial = 67	47	290,897	0	290,897	0	1547-2345 8.0 Hrs	36,362
22 FEB	1335	29	600,989	114,833	486,156	19.1	0 to 2345 23.75 Hrs	25,305
23 FEB	1335	20	370,885	201,527	169,358	54.3	0 to 2345 23.75 Hrs	15,616
24 FEB	1145	25	408,019	115,129	292,890	28.2 0 to 1434 9.4 Hrs	0 to 1434 1700 to 2350 21.40 Hrs	19,066

Date	Solar Insolarion (BTU/SF/Day) Cum, Horizontal	Degree Days	House Heating Demand (BTU's)				Time Interval Analysis	Average Hourly Heating Demand BTU's/Hour
			Total	Solar	Gas	% Solar		
25 FEB	1170	25	422,237	211,038	211,199	49.9	0 to 1730 1800 to 2350 23.3 Hrs	18,096
26 FEB	1194	21	459,415	116,715	342,700	25.4	0 to 2350 23.83 Hrs	19,303
27 FEB	670	22	344,692	0	344,692	0.0	0 to 1530 15.5 Hrs	22,238
28 FEB	1014	22	121,756	105,816	15,940	86.9	0928 to 2350 14.37 Hrs	8,473
29 FEB	1335	26	544,864	339,642	205,222	62.3	0 to 1721 1740 to 2350 23.52 Hrs	23,169

SOLAR TEST HOUSE

Summary of Data - February 1976

- Days of Record Considered - 24
- Total Hours from Above Analyzed - 530
- House Heating Demand (Hourly) - 11,606,483 Btu's (21,899 Btu's/Hour)
- Average Solar Insolation Available - 985 Btu's/SF
- Average Number of Degree Days - 26 (Therefore, average outside temperature = 39°F)
- Btu's Available to the Solar Arrays - 17,999,280 (15% of Heating Demand)
- Btu's Collected by the Solar Arrays and Storage Tank - 7,392,805 (64% of Heating Demand and 41% of that Available)
- Btu's Provided to the House for Heating by the Solar Energy System - 2,506,955
  - Based on 100% Furnace Efficiency - 22% of Heating Demand
  - Based on 70% Furnace Efficiency - 28% of Heating Demand
- Overall System Performance - 34% (Btu's Provided/Btu's Collected)

Date	Solar Insolation (BTU/SF/Day) Cum, Horizontal	Degree Days	Storage Tank Temp Daily		(45°) Ground Array Performance			(52°) Roof Array Performance			Remarks
			Start	Finish	BTU's Available	BTU's Collected	%	BTU's Available	BTU's Collected	%	
1 MAR	1391	24	102°F	118°F	469,347	291,482	62.1	469,927	250,871	53.4	
2 MAR	404	32	101°F	101°F	144,082	24,125	16.7	145,149	22,042	15.2	Marginal Sun
3 MAR	219	45	101°F	101°F	72,792	0	0	72,752	0	0	Cloudy
4 MAR	615	54	98°F	97°F	203,075	0	0	202,837	0	0	Marginal Sun
5 MAR	1224	51	92°F	100°F	402,538	193,236	48.0	401,867	58,820	14.6	
6 MAR	N/A	41	99°F	110°F	N/A	N/A	N/A	N/A	N/A	N/A	No Data from 0640 to 1637hr
7 MAR	1465	35	98°F	110°F	470,126	314,773	67.0	467,993	252,505	54.0	
8 MAR	1472	31	93°F	110°F	468,793	356,112	76.0	466,212	300,557	64.5	
9 MAR	1454	27	96°F	113°F	459,371	331,874	72.2	456,451	280,095	61.5	
10 MAR	1566	24	102°F	116°F	489,854	349,665	71.4	486,122	287,029	59.0	
11 MAR	1276	34	97°F	108°F	396,906	237,656	59.9	393,616	236,960	60.0	Roof Array Recharged
12 MAR	1288	49	101°F	101°F	395,115	152,816	38.7	391,150	104,552	26.7	
13 MAR	1421	37	92°F	111°F	433,389	299,969	69.2	428,734	312,306	72.8	
14 MAR	1494	30	90°F	103°F	449,670	309,988	68.9	444,080	311,650	70.2	
15 MAR	N/A	39	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	Data Not Available, C-19
16 MAR	1407	30	96°F	110°F	417,085	292,261	70.1	411,095	306,850	74.6	
17 MAR	1445	22	99°F	116°F	453,732	282,526	62.3	450,512	291,802	64.8	
18 MAR	1527	14	102°F	118°F	444,954	295,675	66.5	437,562	306,820	70.1	
19 MAR	553	26	116°F	121°F	159,996	84,448	52.8	157,169	92,337	58.8	Cloudy
20 MAR	970	36	104°F	109°F	227,380	174,647	63.0	272,078	207,260	76.3	Overcast
21 MAR	1490	33	102°F	114°F	422,275	228,925	54.2	413,717	225,157	54.4	
22 MAR	1029	29	102°F	110°F	288,765	177,768	61.6	282,521	183,498	65.0	
23 MAR	1174	13	102°F	108°F	326,719	158,800	48.6	319,284	155,655	48.8	

Date	Solar Insolation (BTU/SF/Day) Cum, Horizontal	Degree Days	Storage Tank Temp Daily		Ground Array Performance			Roof Array Performance			Remarks
			Start	Finish	BTU's Available	BTU's Collected	%	BTU's Available	BTU's Collected	%	
24 MAR	Partial - 147	18	103°F	116°F	40,380	29,125	72.1	39,390	35,977	91.3	TTY Paper Tap Malfunction
25 MAR	Partial - 504	21	108°F	122°F	136,907	62,947	46.0	133,328	64,762	48.6	" "
26 MAR	Partial - 71	32	100°F	112°F	18,355	10,453	56.9	17,748	13,346	75.2	" "
27 MAR	1699	27	99°F	112°F	456,761	322,312	70.6	444,170	318,219	71.6	
28 MAR	596	32	94°F	98°F	158,987	49,843	31.4	154,414	52,025	33.7	Overcast
29 MAR	1617	38	91°F	103°F	424,608	267,802	63.1	412,390	148,263	36.0	
30 MAR	1463	35	98°F	103°F	381,096	180,611	47.4	368,818	178,824	48.5	
31 MAR	1901	30	98°F	117°F	492,243	362,973	73.7	475,974	364,356	76.5	

Date	Solar Insolarion (BTU/SF/Day) Cum, Horizontal	Degree Days	House Heating Demand (BTU's)				Time Interval Analysis	Average Hourly Heating Demand BTU's/Hour
			Total	Solar	Gas	% Solar		
1 MAR	1391	24	583,263	240,563	342,700	41.2	21.49	27,141
2 MAR	404	32	224,841	89,964	134,887	40.0	10.93	20,571
3 MAR	219	45	623,398	0	623,398	0	16.67	37,396
4 MAR	615	54	929,341	0	929,341	0	23.35	39,800
5 MAR	1224	51	899,733	0	899,733	0	23.83	37,756
6 MAR	N/A	41	512,906	128,010	384,896	25.0	14.00	36,636
7 MAR	1465	35	588,045	229,467	358,578	39.0	23.75	24,760
8 MAR	1472	31	433,884	236,504	197,380	54.5	23.75	18,269
9 MAR	1454	27	430,615	216,785	213,830	50.3	23.32	18,465
10 MAR	1566	24	333,695	139,602	194,093	41.8	23.75	14,050
11 MAR	1276	34	391,508	302,686	88,822	77.3	23.95	16,347
12 MAR	1288	49	798,784	229,665	569,119	28.8	23.83	33,520
13 MAR	1421	37	589,719	111,068	478,651	18.8	23.75	24,830
14 MAR	1494	30	465,606	306,055	159,551	65.7	23.90	19,481
15 MAR	N/A	39	119,142	5,648	113,494	4.7	4.22	28,233
16 MAR	1407	30	452,129	82,037	370,092	18.1	21.88	20,664
17 MAR	1445	22	289,766	61,132	228,634	21.1	23.25	12,463
18 MAR	1527	14	210,809	126,920	83,889	60.2	23.80	8,857
19 MAR	553	26	382,748	325,178	57,570	85.0	17.55	21,809
20 MAR	970	36	239,440	172,001	67,439	71.8	23.80	10,060
21 MAR	1490	33	483,378	123,155	360,223	25.5	23.78	20,324

Date	Solar Insolarion (BTU/SF/Day) Cum, Horizontal	Degree Days	House Heating Demand (BTU's)				Time Interval Analysis	Average Hourly Heating Demand BTU's/Hour
			Total	Solar	Gas	% Solar		
22 MAR	1029	29	528,285	115,427	412,858	21.8	20.50	25,770
23 MAR	1174	13	287,452	7,827	279,625	2.7	23.75	12,103
24 MAR	Partial - 147	18	31,210	21,210	0	100.0	5.00	6,242
25 MAR	Partial - 504	21	20,212	20,212	0	100.0	11.73	1,723
26 MAR	Partial - 71	32	117,409	117,409	0	100.0	7.55	15,551
27 MAR	1699	27	511,631	197,464	314,167	38.6	23.75	21,542
28 MAR	596	32	595,347	119,985	475,362	20.2	23.75	25,067
29 MAR	1617	38	656,296	0	656,296	0	23.26	28,216
30 MAR	1463	35	742,877	15,877	727,024	2.1	23.45	31,679
31 MAR	901	30	594,314	150,204	444,110	25.3	23.75	25,024

SOLAR TEST HOUSE

Summary of Data - March 1976

- Days of Record Considered - 29
- Total Hours from Above Analyzed - 625
- House Heating Demand (Hourly) - 14,067,783 Btu's (22,507 Btu's/Hour)
- Average Solar Insolation Available - 32 (Therefore, average outside temperature = 33^{8}F)
- Btu's Available to the Solar Arrays - 19,322,361 (13% of Heating Demand)
- Btu's Collected by the Solar Arrays and Storage Tank - 10,889,943 (77% of Heating Demand and 56.4% of that Available)
- Btu's Provided to the House for Heating by the Solar Energy System - 3,902,031
  - Based on 100% Furnace Efficiency - 27.7% of Heating Demand
  - Based on 70% Furnace Efficiency - 35.0% of Heating Demand
- Overall System Performance - 36% (Btu's Provided/Btu's Collected)

Date	Solar Insolarion (BTU/SF/Day) Cum, Horizontal	Degree Days	House Heating Demand (BTU's)				Time Interval Analysis (Hours)	Average Hourly Heating Demand BTU's/Hour
			Total	Solar	Gas	% Solar		
1 APR	1899	20	261,977	130,388	131,589	49.8	20.50	12,799
2 APR	1562	14	178,899	160,805	18,094	89.9	23.75	7,533
3 APR	1892	24	363,654	195,879	165,775	53.9	23.75	15,312
4 APR	1160	23	350,706	283,267	67,439	80.9	23.38	14,998
5 APR	1306	18	279,205	43,991	235,214	15.8	23.75	11,756
6 APR	1909	26	385,555	168,434	217,121	43.7	23.75	16,234
7 APR	1571	24	295,058	295,058	0	100.0	21.75	13,566
8 APR	1941	17	333,896	333,896	0	100.0	23.80	14,029
9 APR	N/A	24	N/A	N/A	N/A	N/A	N/A	N/A
10 APR	N/A	15	N/A	N/A	N/A	N/A	N/A	N/A
11 APR	1821	21	96,503	96,503	0	100.0	16.25	5,939
12 APR	1495	14	183,098	183,098	0	100.0	20.25	9,042
13 APR	1683	17	229,371	188,250	0	82.1	23.75	9,658
14 APR	911	16	309,795	135,441	174,354	43.7	24.00	12,908
15 APR	393	23	304,298	0	304,298	0	12.28	24,773
16 APR	N/A	21	89,667	89,667	0	100.0	4.75	18,877
17 APR	283	30	404,561	157,833	246,728	39.0	21.50	18,817
18 APR	1854	33	465,493	0	465,493	0	23.75	19,600
19 APR	1505	25	432,596	0	432,596	0	23.83	18,151
20 APR	2044	23	372,423	91,153	281,270	24.5	22.83	16,310
21 APR	1298	16	229,848	167,344	62,504	72.8	23.83	9,645
22 APR	1763	17	195,737	0	195,737	0	23.83	8,213

Date	Solar Insolarion (BTU/SF/Day) Cum, Horizontal	Degree Days	House Heating Demand (BTU's)				Time Interval Analysis (Hours)	Average Hourly Heating Demand BTU's/Hour
			Total	Solar	Gas	% Solar		
23 APR	917	18	250,563	56,475	194,093	22.5	20.88	11,999
24 APR	2181	20	300,091	59,943	240,148	20.0	23.75	12,635
25 APR	1962	23	242,744	242,744	0	100.0	22.73	10,678
26 APR	1681	14	320,467	256,318	64,149	79.9	22.70	14,118
27 APR	1461	22	352,196	243,635	108,561	69.2	23.75	14,829
28 APR	981	23	554,315	0	554,315	0	23.80	23,291
29 APR	307	22	379,961	0	379,961	0	21.50	17,673
30 APR	1195	26	559,250	0	559,250	0	23.75	23,547

Date	Solar Insolation (BTU/SF/Day) Cum, Horizontal	Degree Days	Storage Tank Temp Daily		Ground Array Performance			Roof Array Performance			Remarks
			Start °F	Finish °F	BTU's Available	BTU's Collected	%	BTU's Available	BTU's Collected	%	
1 APR	1899	20	97	120	489,121	354,136	72.4	472,587	364,067	77.0	
2 APR	1562	14	102	117	397,227	257,295	64.8	383,022	286,669	74.8	
3 APR	1892	24	102	120	479,612	324,737	67.7	462,237	346,396	74.9	
4 APR	1160	23	98	108	291,397	176,368	60.5	280,437	190,220	67.8	
5 APR	1306	18	102	113	324,459	178,543	55.0	311,720	191,260	61.4	
6 APR	1909	26	100	116	470,038	316,541	67.3	450,937	319,604	70.9	
7 APR	1571	24	95	112	388,676	259,321	66.7	373,100	290,829	77.9	
8 APR	1941	17	92	110	469,895	344,114	73.2	449,549	348,189	77.5	
9 APR	N/A	24	102	117	N/A	N/A	N/A	N/A	N/A	N/A	TTY Paper Tape Malfunction
10 APR	N/A	15	100	126	N/A	N/A	N/A	N/A	N/A	N/A	" "
11 APR	1821	21	107	125	439,499	302,139	68.7	420,269	304,401	72.4	
12 APR	1495	14	105	119	358,622	213,969	59.7	342,560	219,114	64.0	
13 APR	1683	17	102	115	393,100	260,934	66.4	373,839	269,038	72.0	
14 APR	911	16	102	108	211,930	94,615	44.6	201,379	86,115	42.8	Overcast
15 APR	393	23	98	98	88,247	638	0.7	83,347	680	0.8	Cloudy
16 APR	N/A	21	99	111	N/A	N/A	N/A	N/A	N/A	N/A	TTY Paper Tape Malfunction
17 APR	283	30	90	90	63,296	1,508	2.4	59,709	0	0	
18 APR	1854	33	87	99	423,891	350,000	82.6	401,605	55,367	13.8	Roof Array Malfunction
19 APR	1505	25	92	102	341,362	-198,975	-58.3	322,957	182,847	56.6	Ground Array Malfunction
20 APR	2034	23	96	113	463,691	262,095	56.5	436,786	325,067	74.4	
21 APR	1298	16	92	103	277,299	178,386	64.3	259,456	189,753	73.1	
22 APR	1763	17	96	110	382,742	217,912	56.9	359,232	277,885	77.4	

Date	Solar Insolation (BTU/SF/Day) Cum, Horizontal	Degree Days	Storage Tank Temp Daily		Ground Array Performance			Roof Array Performance			Remarks
			Start °F	Finish °F	BTU's Available	BTU's Collected	%	BTU's Available	BTU's Collected	%	
23 APR	917	18	100	106	186,284	89,759	48.2	172,590	111,297	64.5	Power Outage 1230-1530 Ground Array Malfunctions
24 APR	2181	20	100	119	463,248	80,731	17.4	432,979	326,591	75.4	Ground Array Still Bad
25 APR	1962	23	100	116	416,223	235,956	56.7	388,921	263,386	67.7	
26 APR	1681	14	99	115	354,961	240,090	67.6	331,382	221,347	66.8	Pyranometer Peculiar
27 APR	1461	22	95	106	317,923	211,400	66.5	298,535	196,182	65.7	
28 APR	981	23	99	100	171,231	74,033	43.2	153,351	51,630	33.7	
29 APR	307	22	97	90	59,906	-40,013	N/A	55,066	0	0	Overcast/Rainy GA Sensor MF
30 APR	1195	26	86	94	228,117	- 2,399	53.4	208,606	159,715	76.6	GA Sensor MF

SOLAR TEST HOUSE

Summary of Data - April 1976

- Days of Record Considered	- [illegible]
- Total Hours from Above Analyzed	- 608
- House Heating Demand (Hourly)	- 8,721,932 Btu's (14,342 Btu's/Hour)
- Average Solar Insolation Available	- 1445 Btu's/SF
- Average Number of Degree Days	- 21 (Therefore, average outside temperature = 44°F)
- Btu's Available to the Solar Arrays	- 17,438,155 (200% of Heating Demand)
- Btu's Collected by the Solar Arrays and Storage Tank	- 10,361,577 (119% of Heating Demand and 59.4% of that Available)
- Btu's Provided to the House for Heating by the Solar Energy System	- 3,580,112
Based on 100% Furnace Efficiency	- 41.1% of Heating Demand
Based on 70% Furnace Efficiency	- 50.0% of Heating Demand
- Overall System Performance	- 35% (Btu's Provided/Btu's Collected)

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APPENDIX G

SELECTED SOLAR ENERGY SYSTEM COMPUTER ACQUIRED PERFORMANCE PLOTS

DAY SELECTED	PAGE NO.
22 December 1975	G-4
19 January 1976	G-8
23 February 1976	G-12
21 March 1976	G-16
21 April 1976	G-20

For each day selected, the following four plots have been selected:

a. Energy Available

b. Ground Array

c. Roof Array

d. House Heating Demand

The legends for the plots are shown below.

LEGEND FOR HOUSE HEATING DEMAND

(1) = Actual house temperature - ^{o}F

(2) = Desired house temperature - ^{o}F

(3) = $\frac{\text{Heat Coil But's}}{100}$ into house since last data point

(4) = $\frac{\text{Gas Btu's}}{100}$ into house since last data point

LEGEND FOR ROOF ARRAY

Corresponds to Ground Array except collection efficiency (2) has a zero base of 100.

LEGEND FOR GROUND ARRAY

(1) = (Btu/SF-min collected) x 10

(2) = $\frac{\text{(Btu/SF-min collected)}}{\text{(Btu/SF-min available)}}$ x 100 = collection efficiency

(3) = Fluid temperature into Ground Array - ^{o}F

(4) = Fluid temperature out of Ground Array - ^{o}F

(5) = Storage tank water temperature - ^{o}F

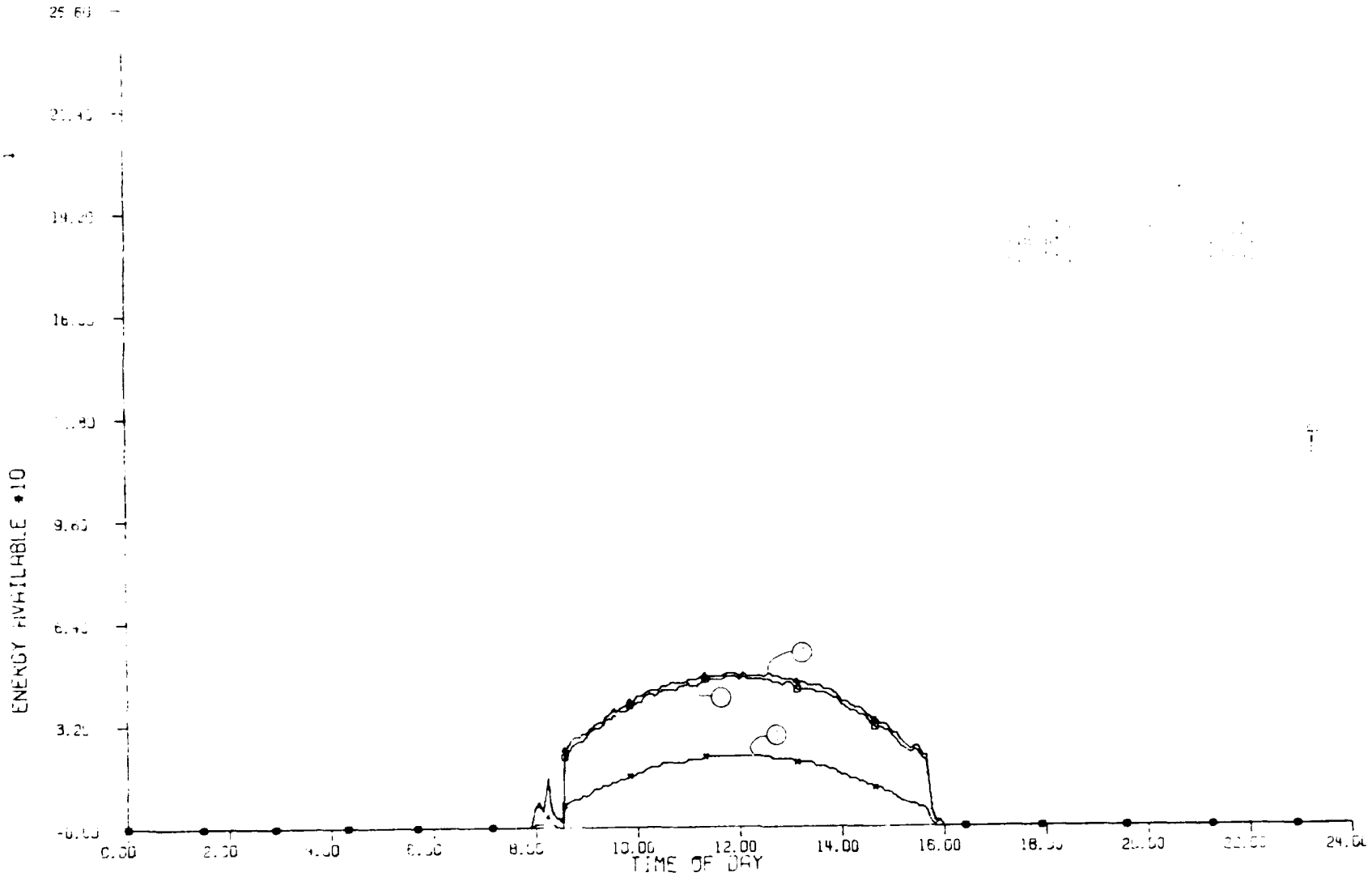
(6) = Flow rate - GPM

LEGEND FOR ENERGY AVAILABLE DATA SUMMARY

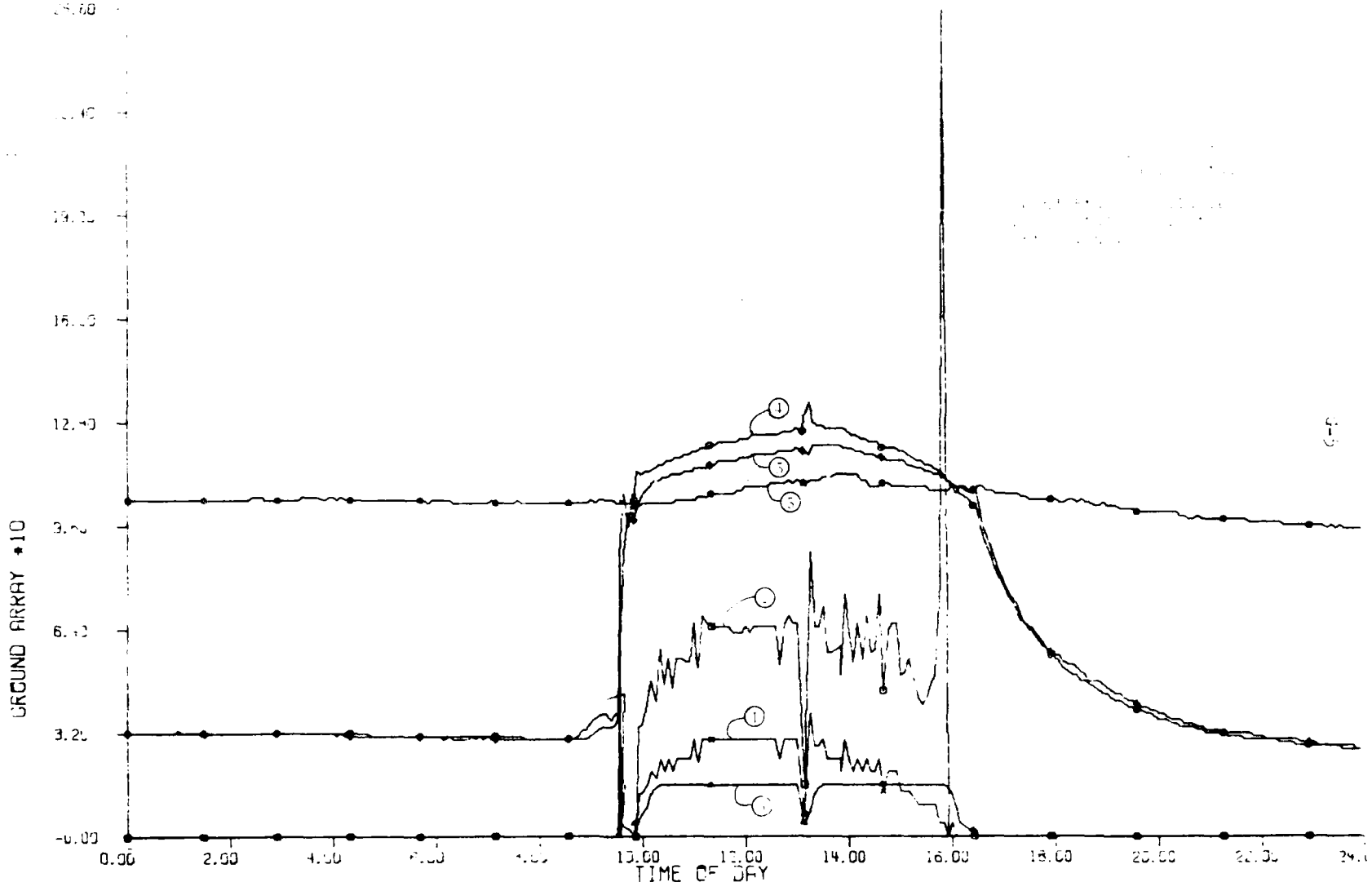
(1) = (Btu/SF-min available horizontal surface) x 10

(2) = (Btu/SF-min available ground array) x 10

(3) = (Btu/SF-min available roof array) x 10



USAFA SOLAR HOUSE



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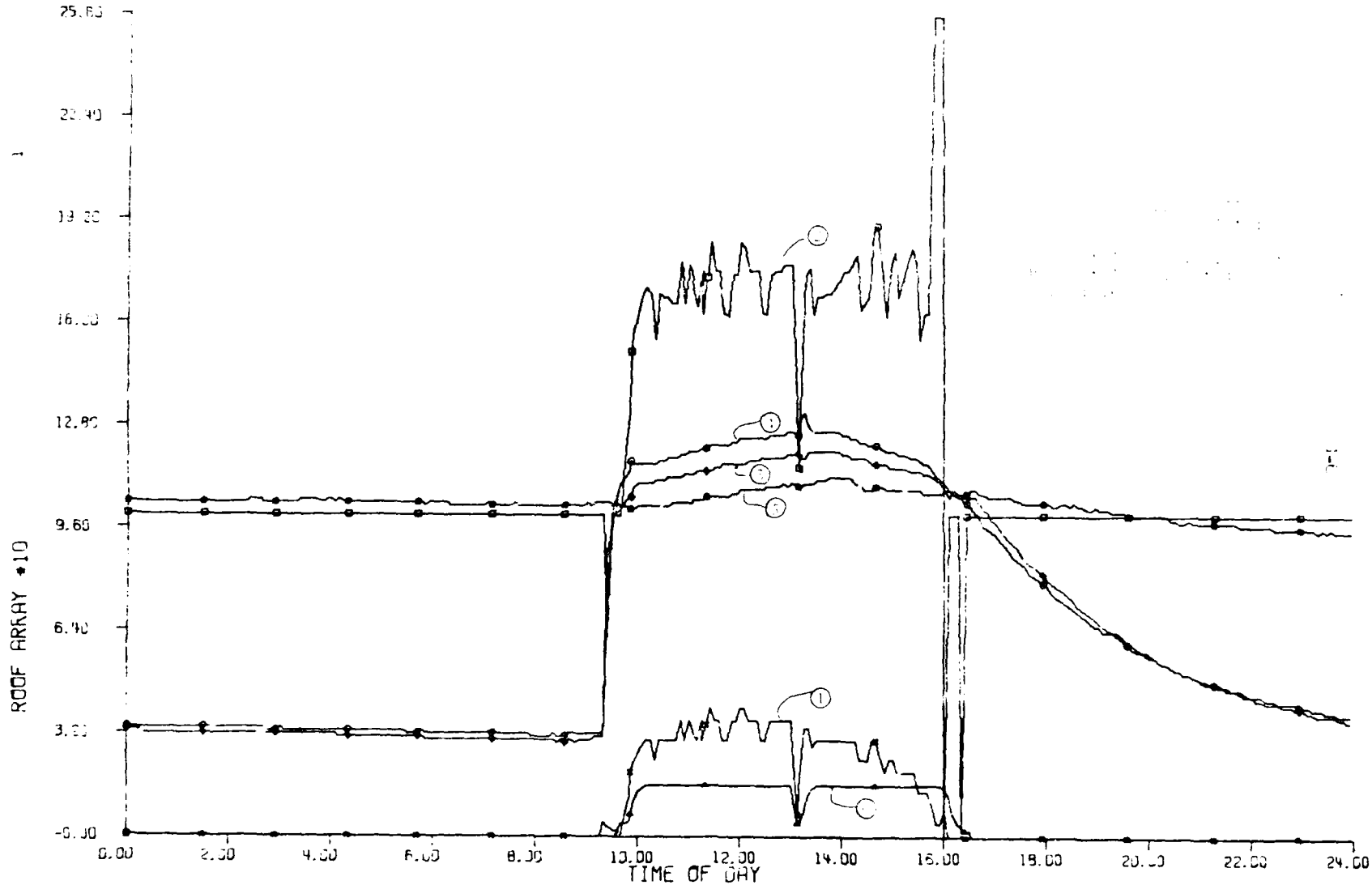
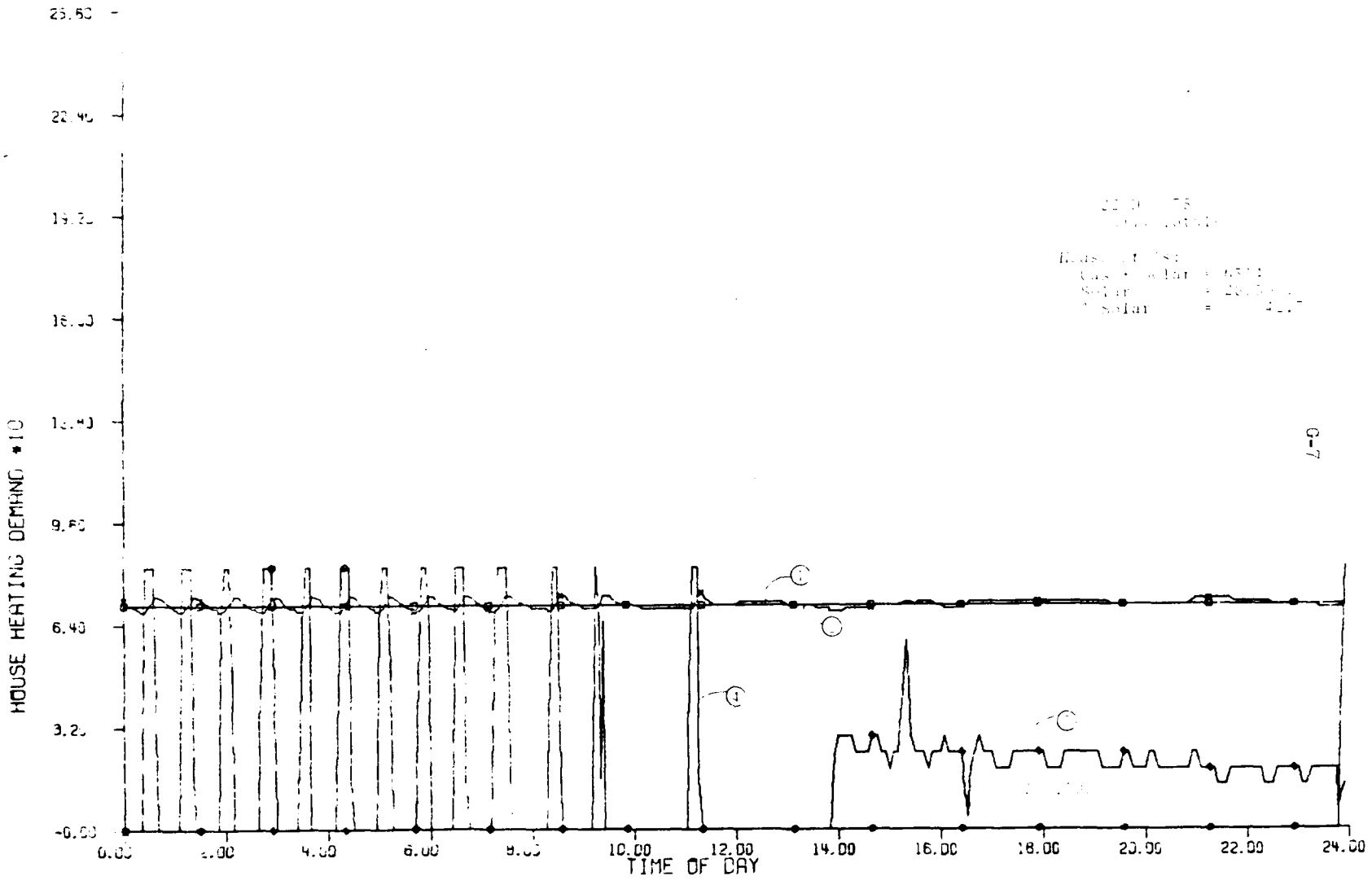

ROOF ARRAY *10
9.60
6.40
0.00
2.00
4.00
6.00
8.00
10.00
12.00
14.00
16.00
18.00
20.00
22.00
24.00
TIME OF DAY

SOLAR HOUSE



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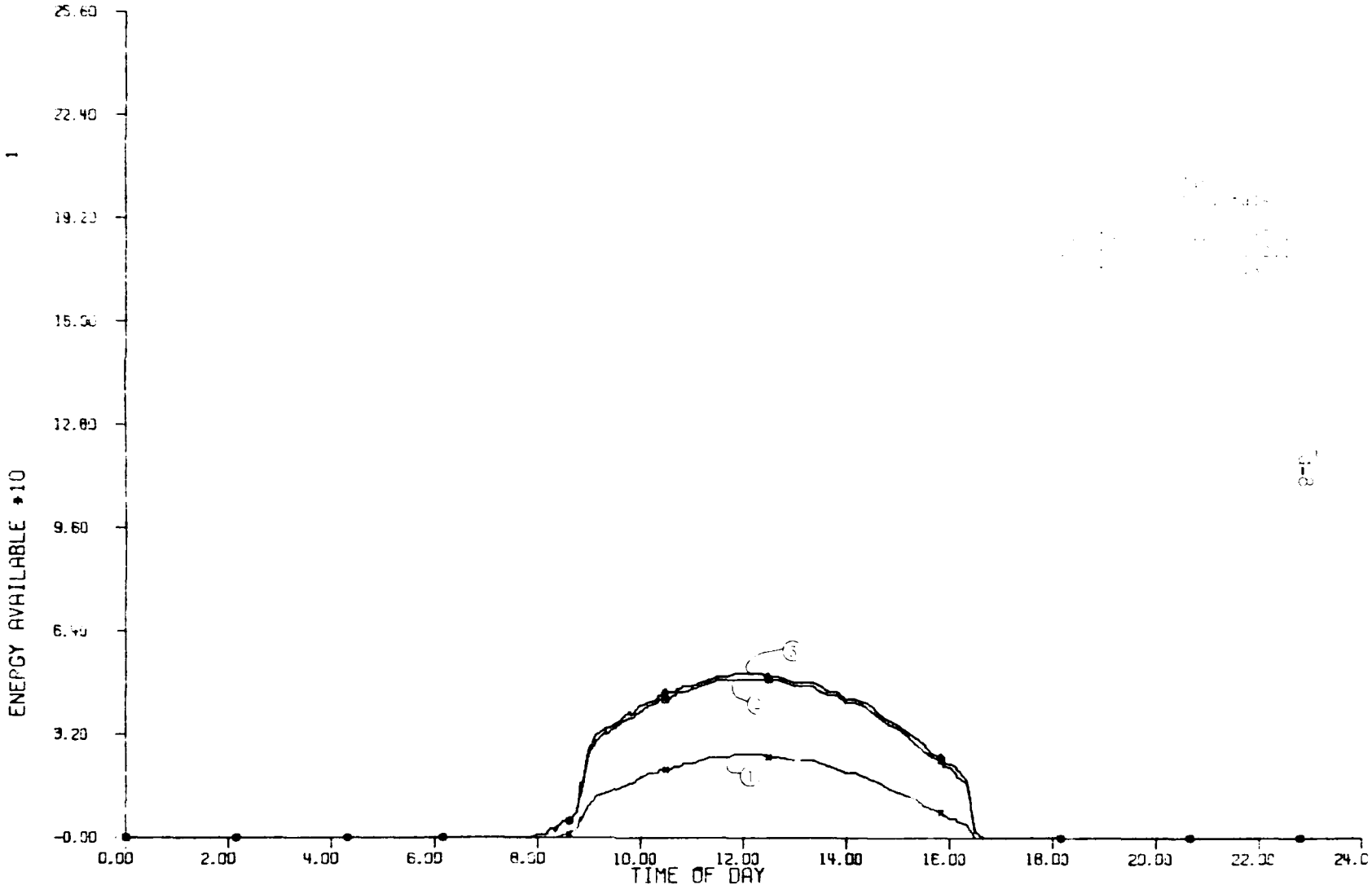

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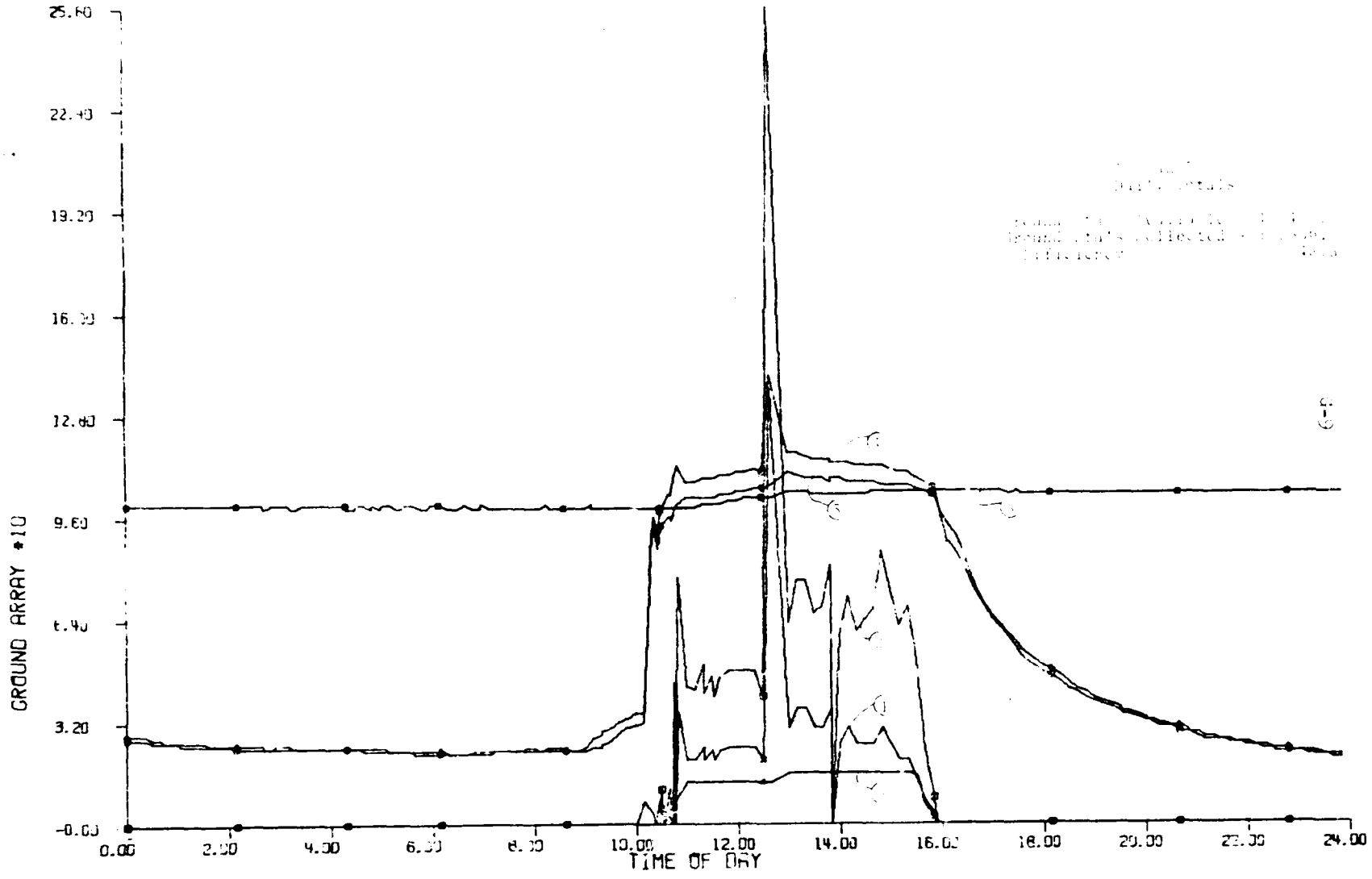

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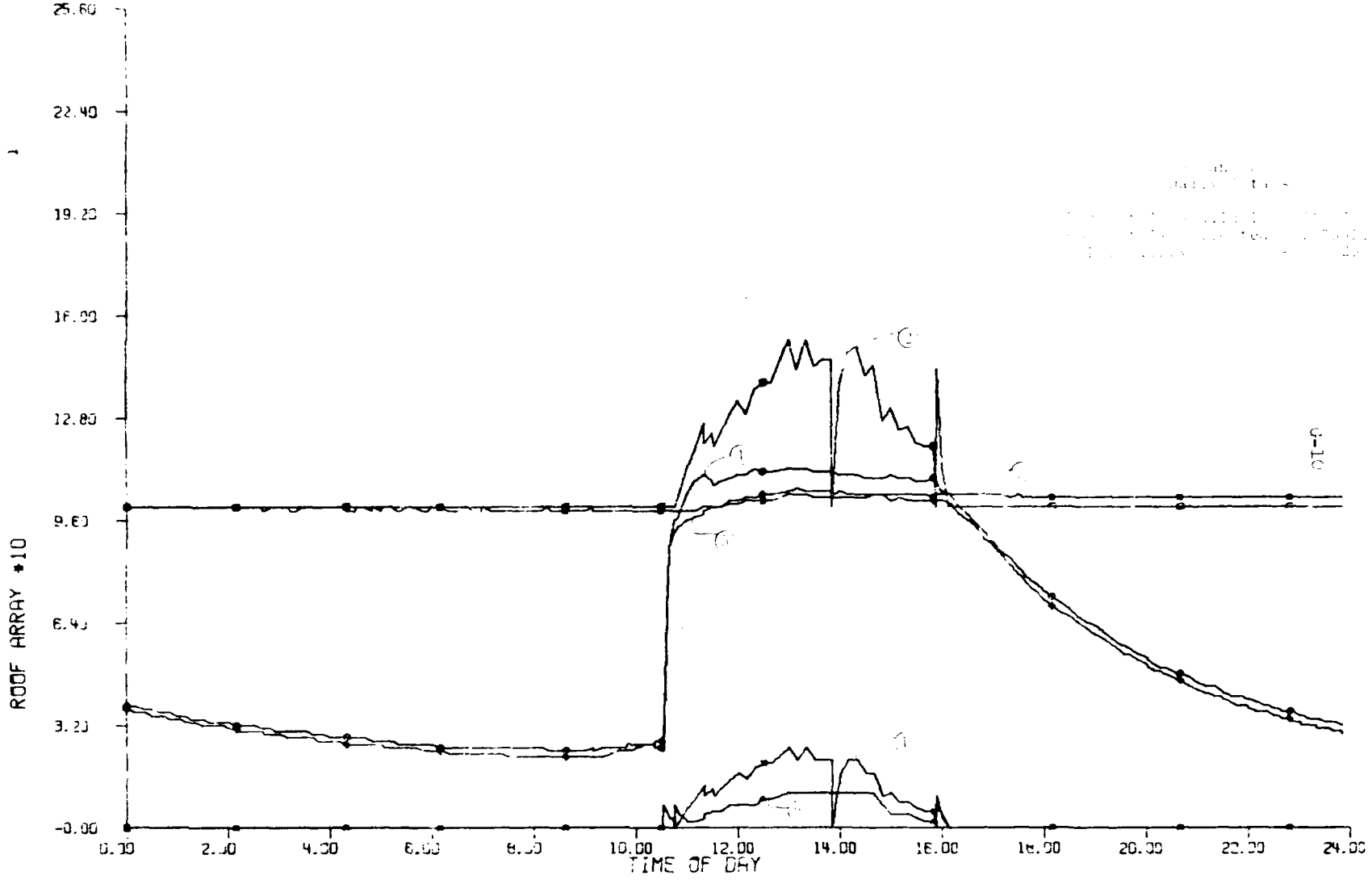
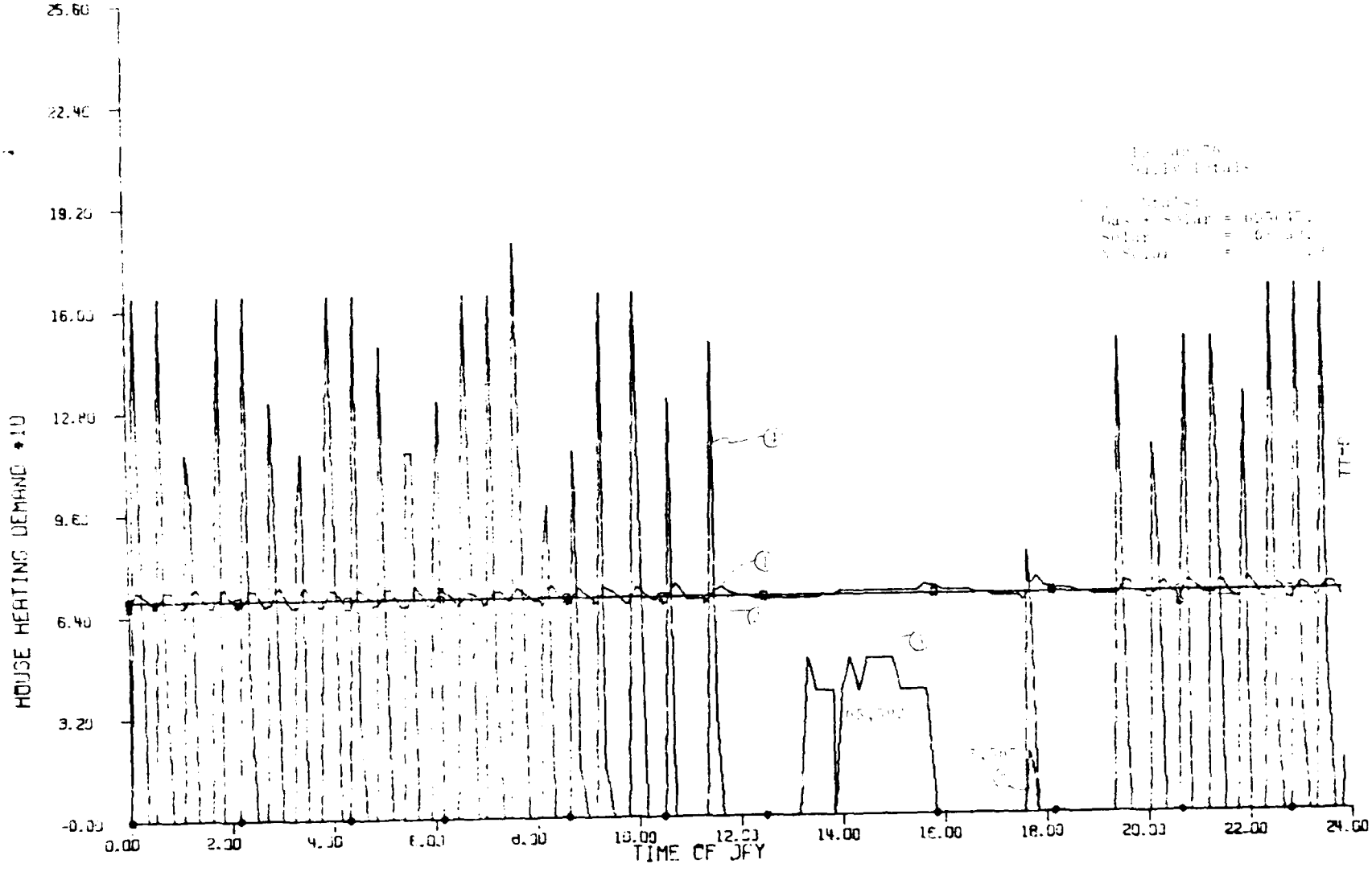
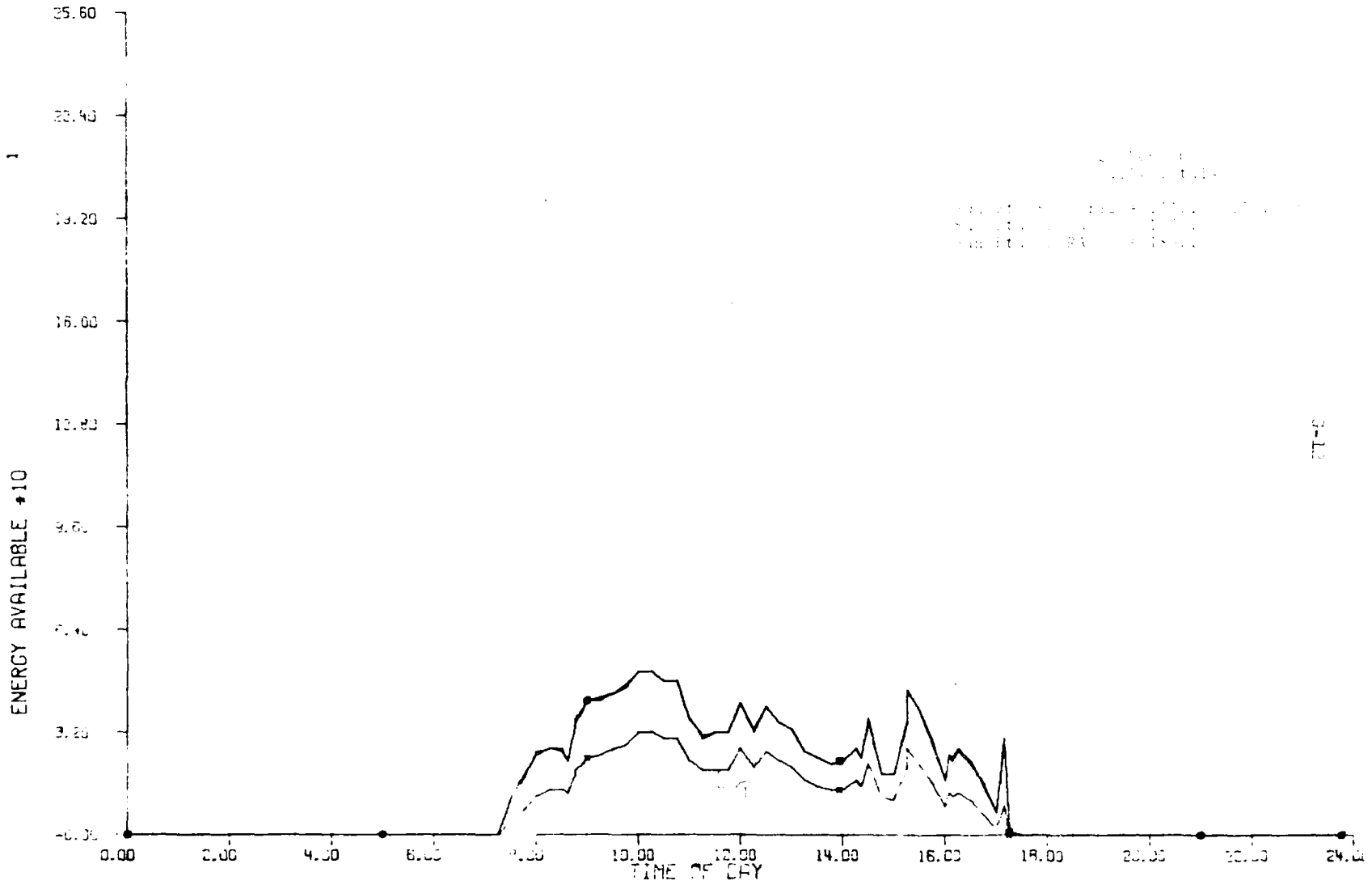
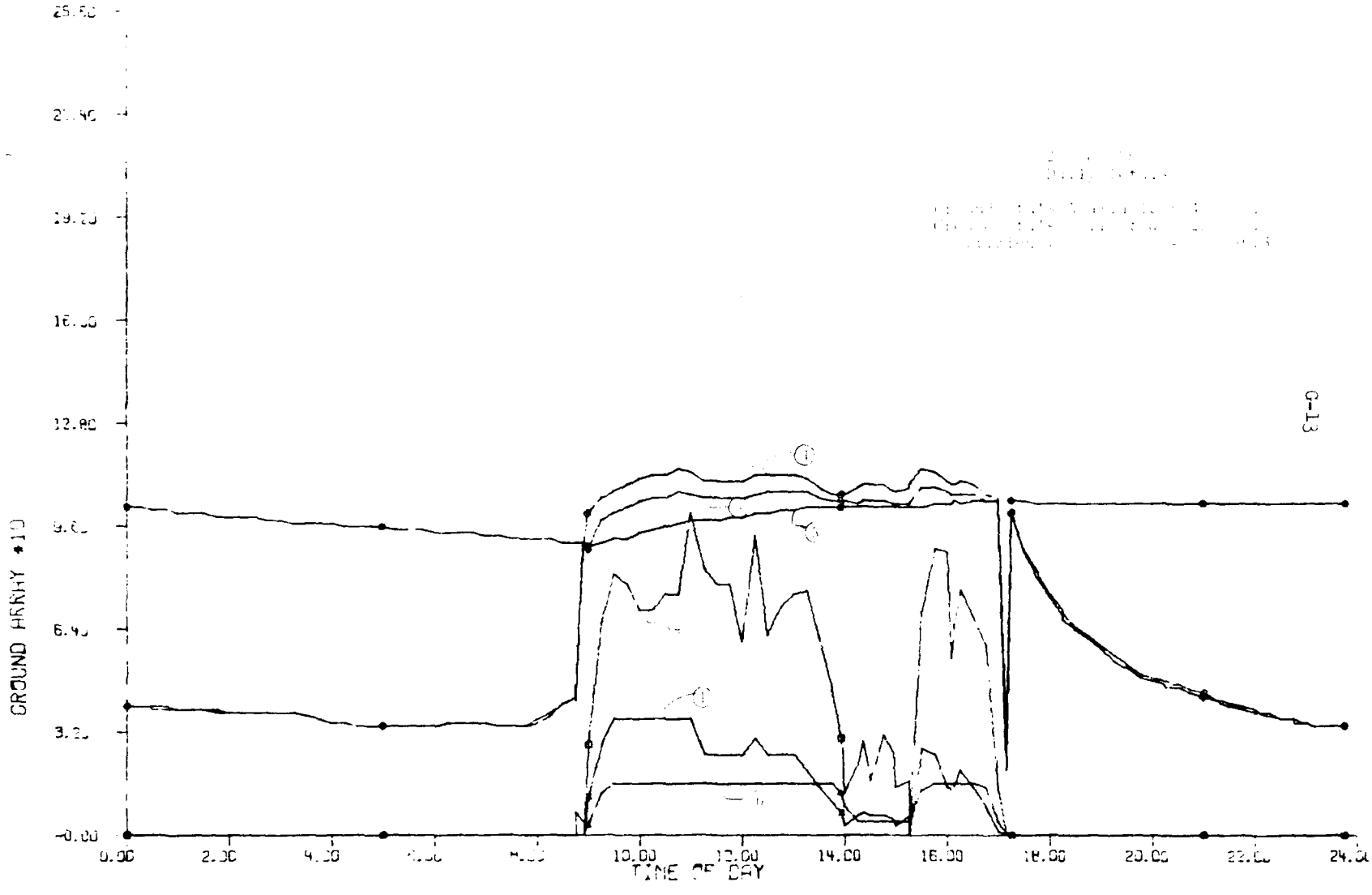


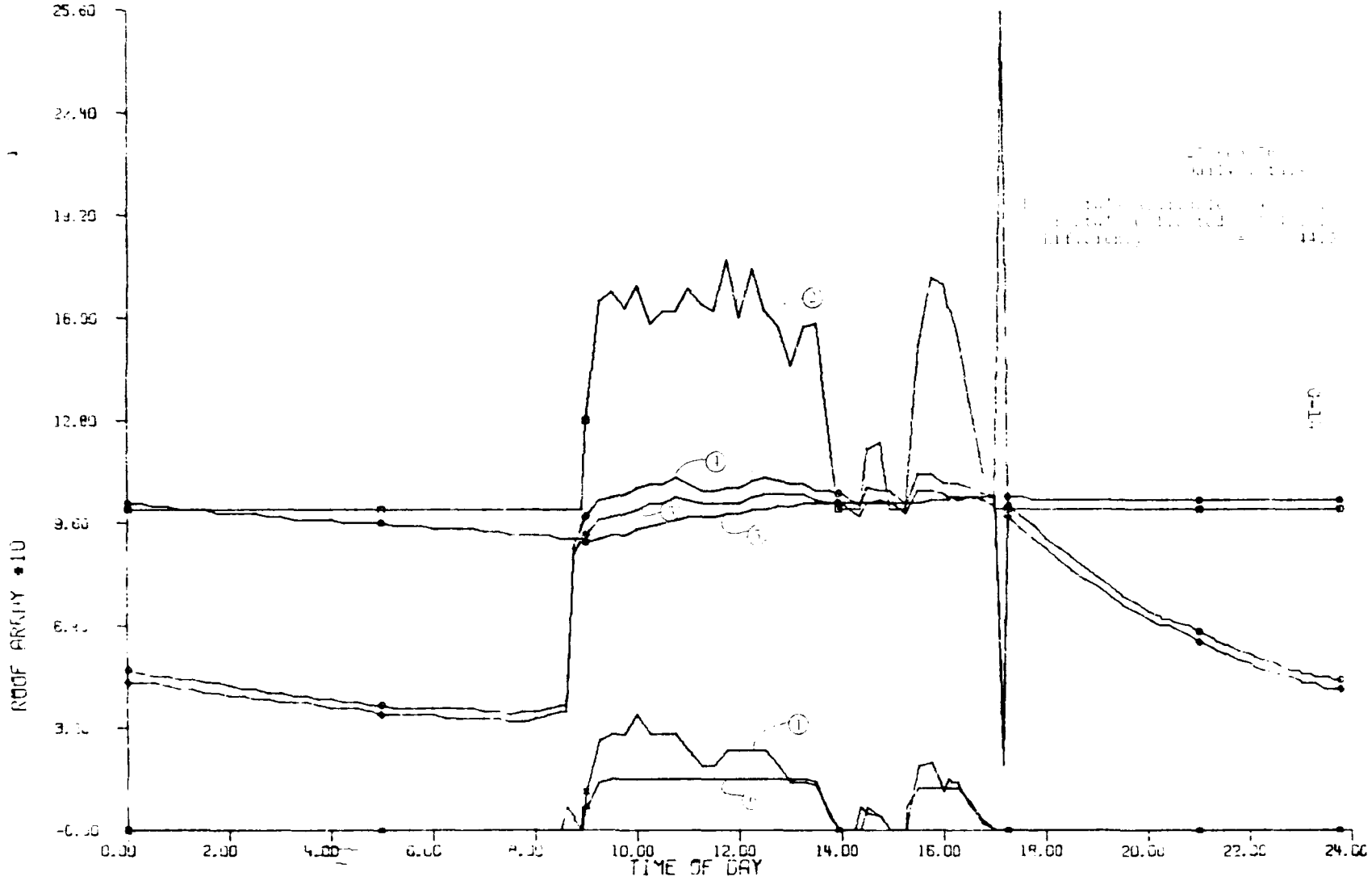
HOAFA SOLAR HOUSE


25.60
22.40
19.20
16.00
12.80
9.60
6.40
3.20
-0.00
HOUSE HEATING DEMAND *10
0.00
2.00
4.00
6.00
8.00
10.00
12.00
14.00
16.00
18.00
20.00
22.00
24.00
TIME OF DAY

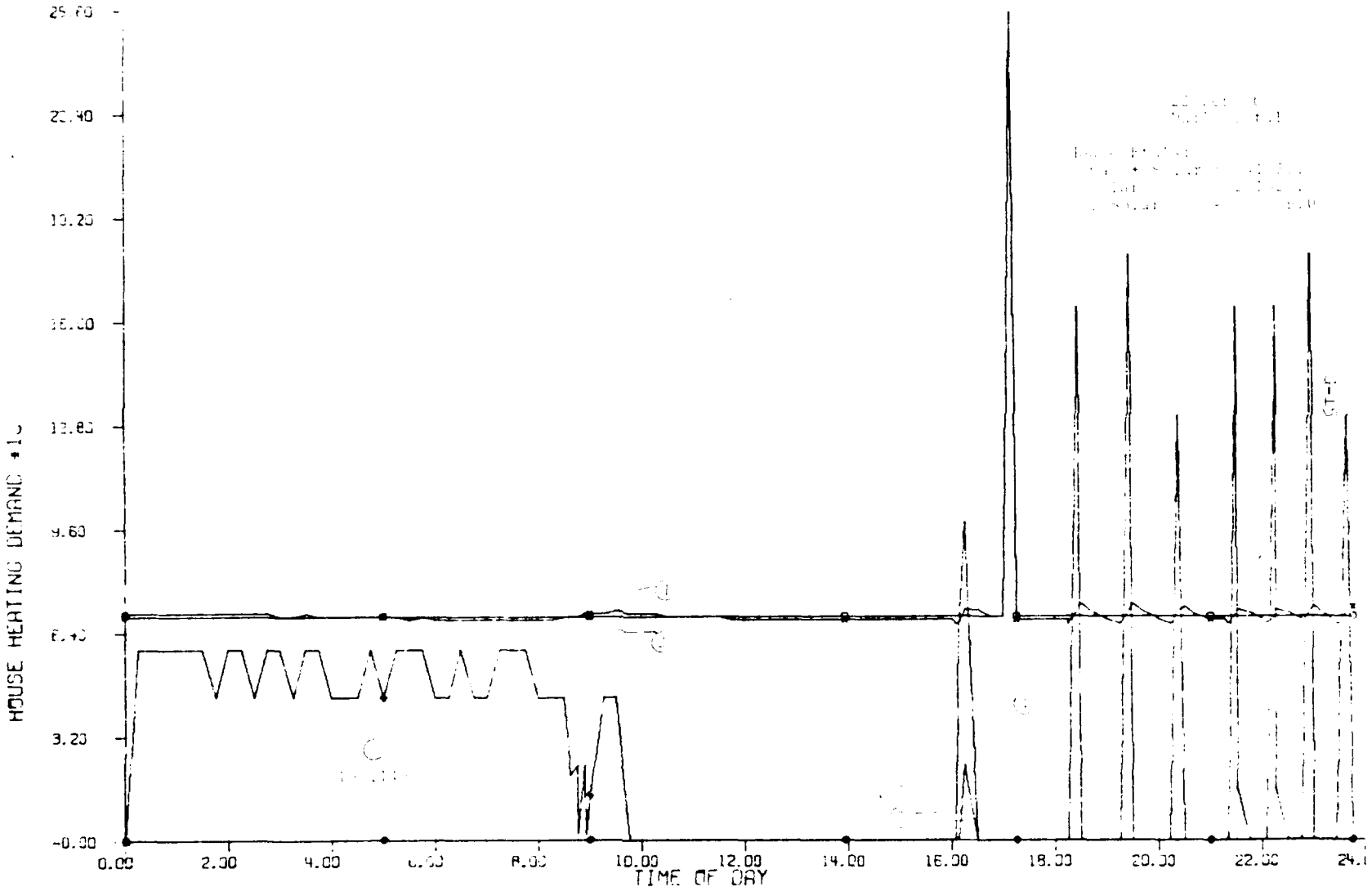
SOLAR HOUSE


ENERGY AVAILABLE *10
TIME OF DAY
0.00
2.00
4.00
16.00
18.00
24.00


GROUND ARRAY #10
TIME OF DAY
0.00
2.00
4.00
10.00
14.00
16.00
18.00
20.00
24.00
12.80
6.40
3.20
-0.00

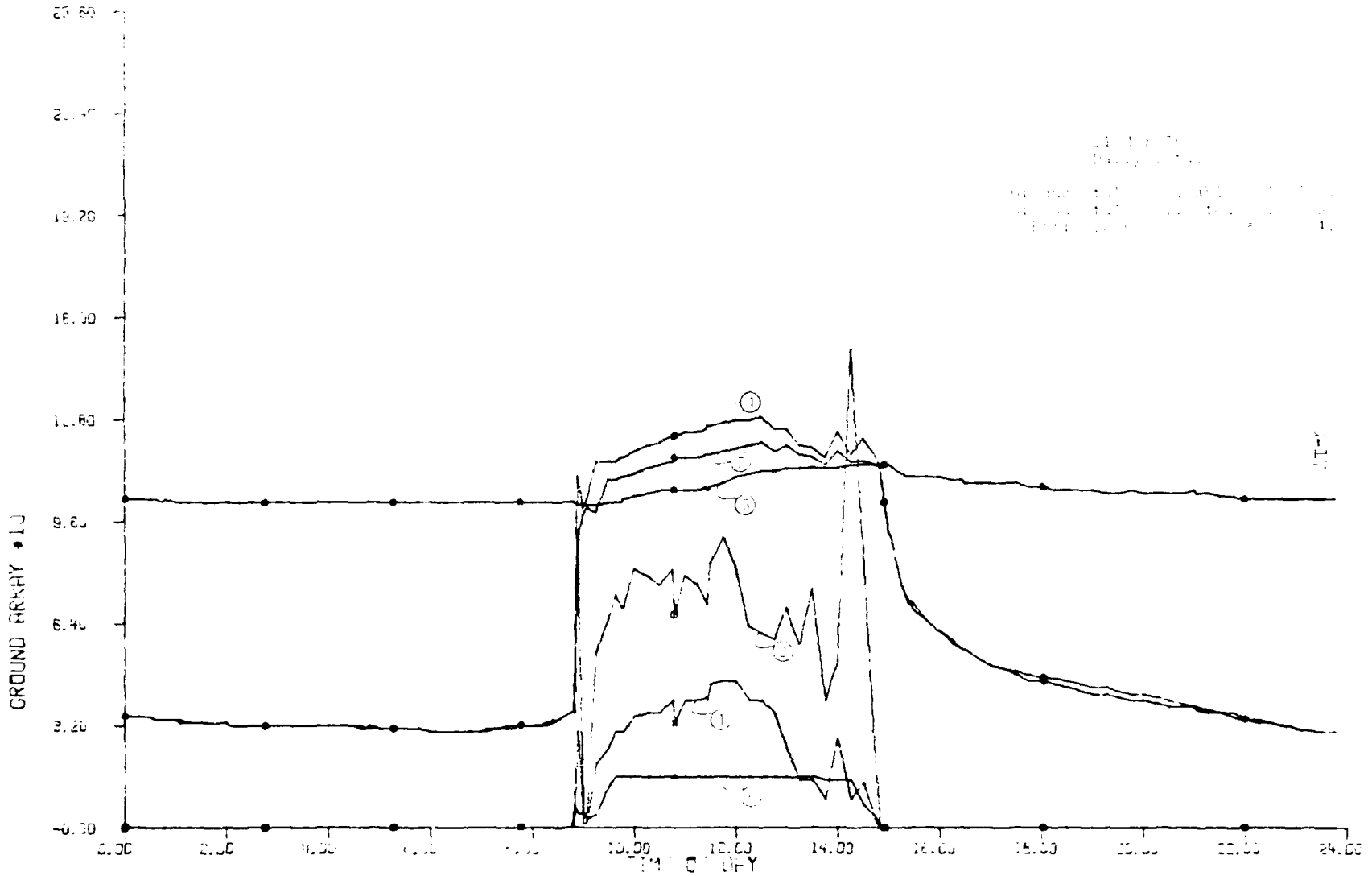


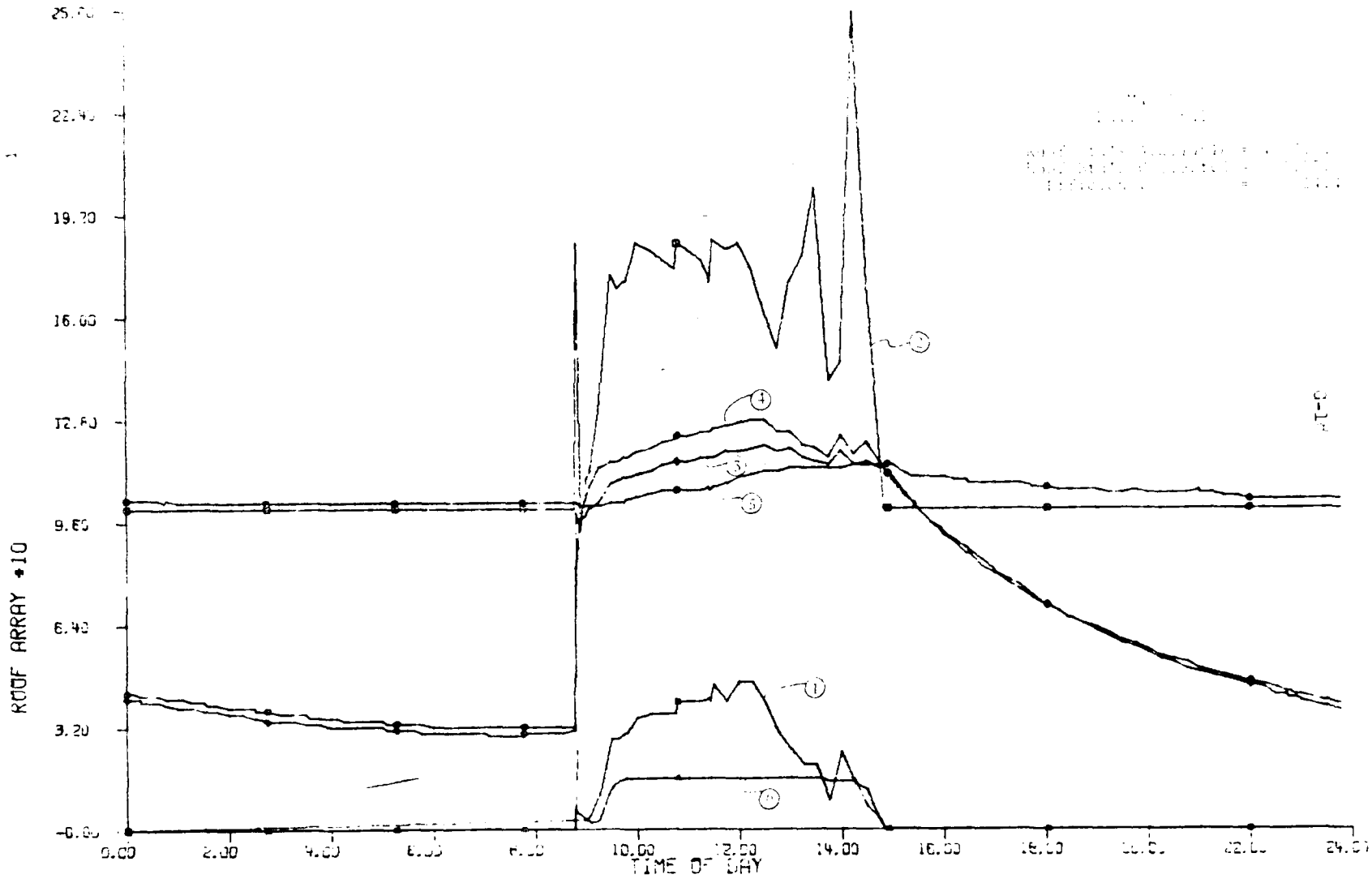
UPPER SOLAR HOUSE



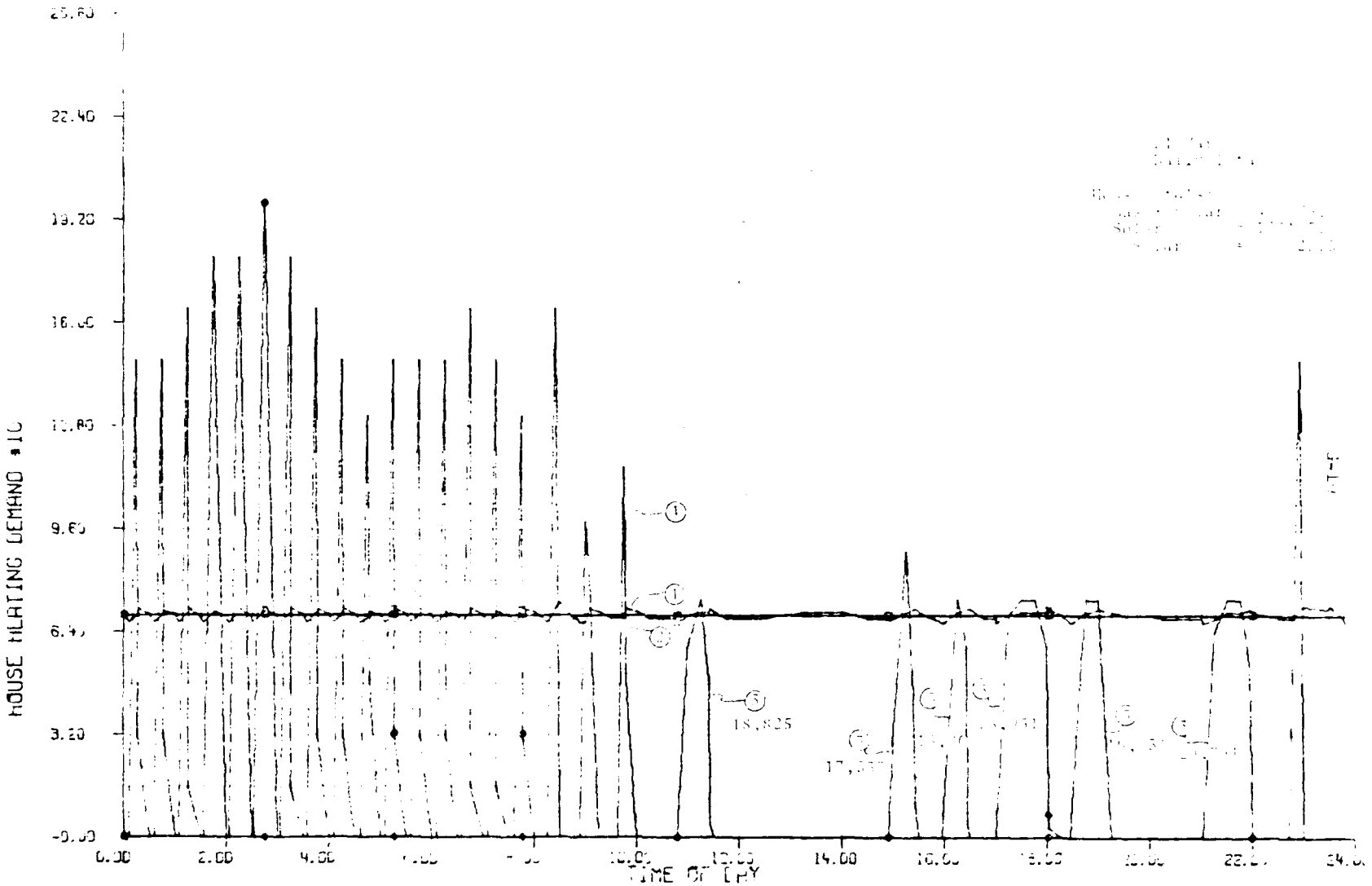
USAFA SOLAR HOUSE

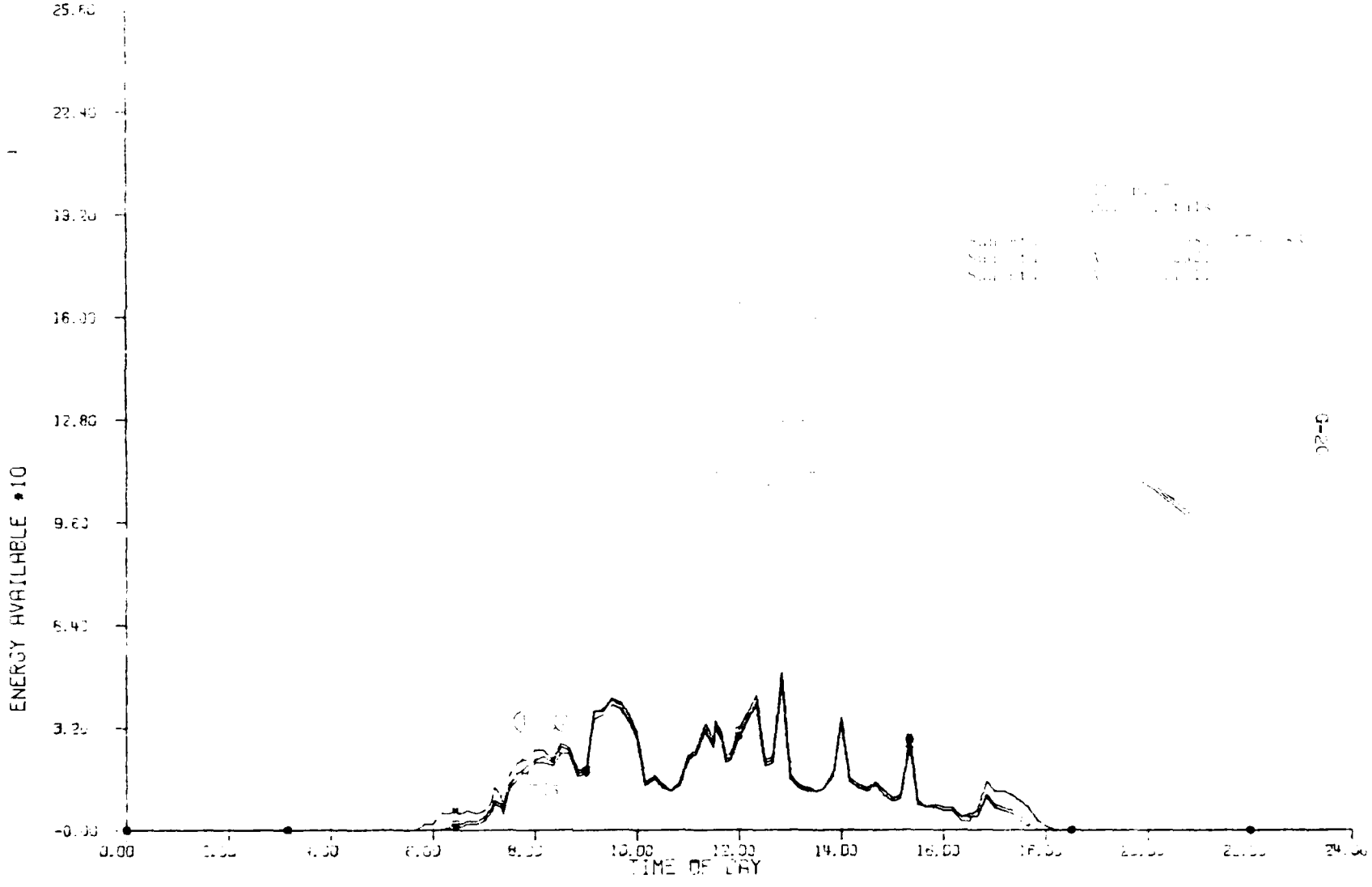
ENERGY AVAILABLE TO

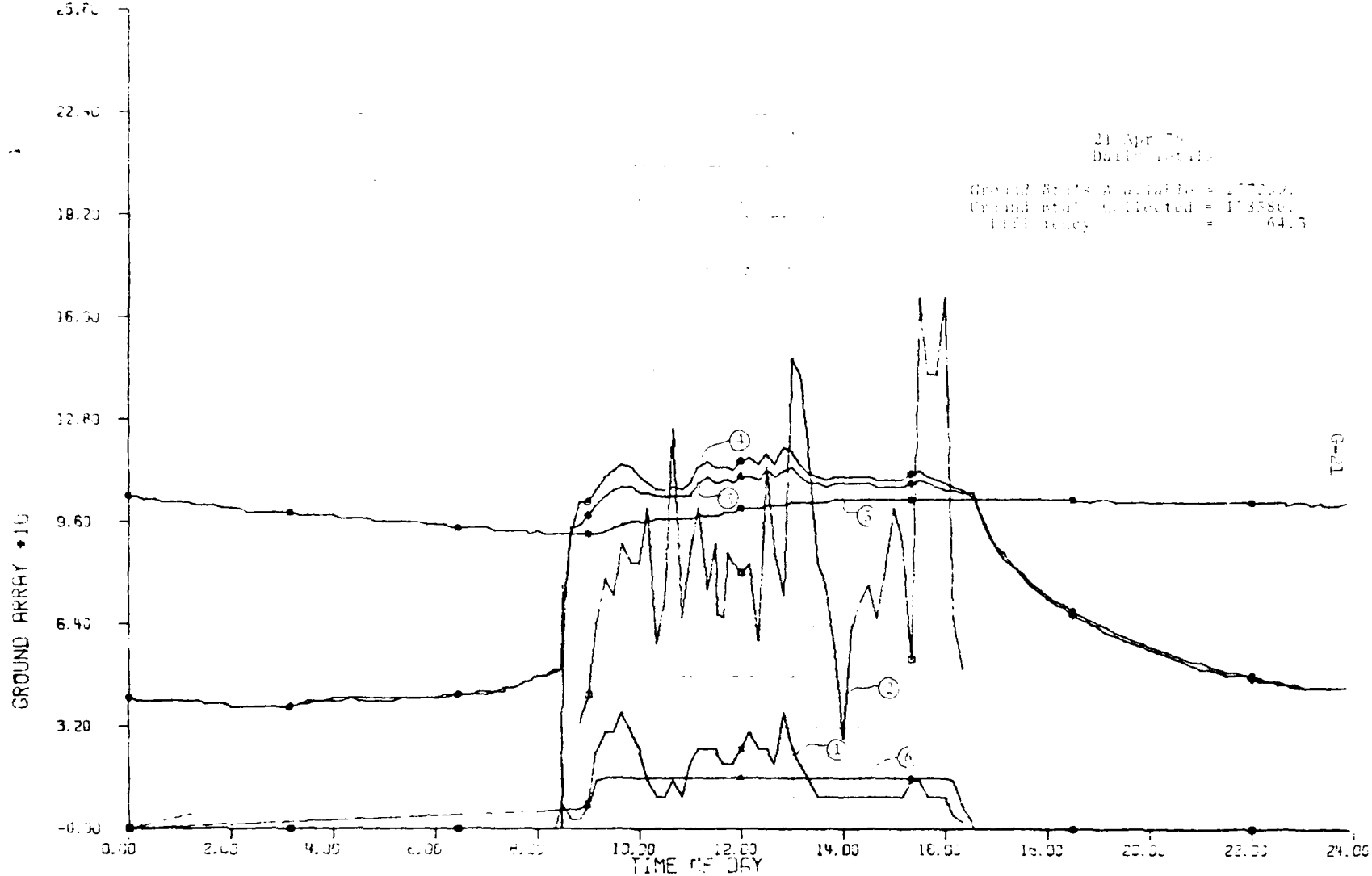

GROUND ARRAY #10
TIME OF DAY
14.00
24.00


ROOF ARRAY #10
TIME OF DAY
0.00
2.00
4.00
10.00
14.00
19.20
16.00
9.60
6.40
3.20
1
2
3
4
5
6

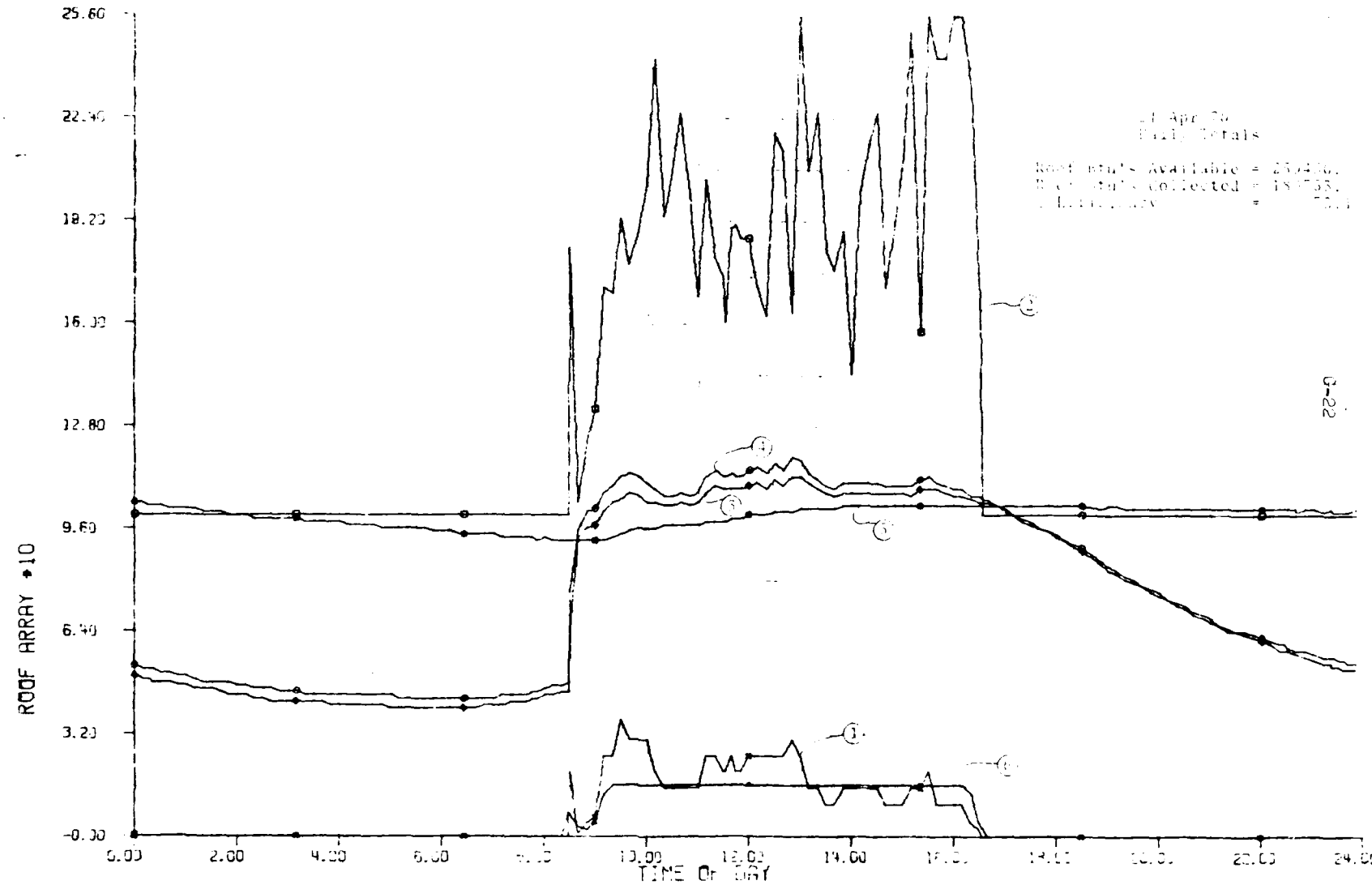
[illegible] HOUSE


HOUSE HEATING DEMAND * 10
22.40
19.20
16.00
12.80
9.60
6.40
3.20
-0.00
0.00
2.00
4.00
14.00
TIME OF DAY
18,825

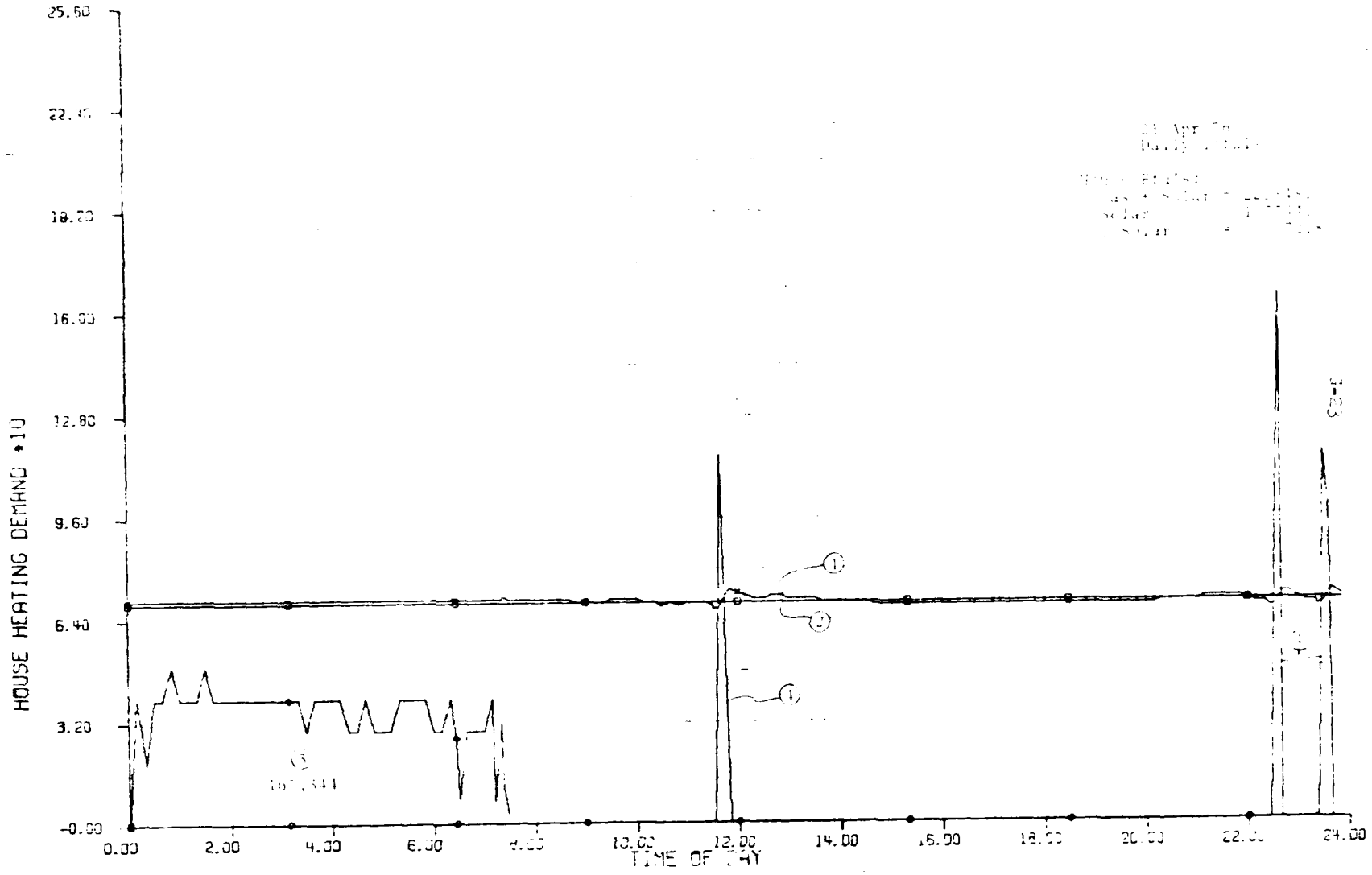

ENERGY AVAILABLE *10
TIME OF DAY
0.00
14.00


GROUND ARRAY
TIME OF DAY
0.00
2.00
4.00
6.00
10.20
12.00
14.00
16.00
24.00
3.20
6.40
9.60
G-21

AR HOUSE



USAFA SOLAR HOUSE



USAFA SOLAR HOUSE

APPENDIX H

PROJECT COST SUMMARY FOR ACQUISITION PHASE

Solar Heating Retrofit of Military Family Housing
AFA 141-5/FJSRL JON 7903-03-75
May 1975

ITEM	COST	WORK DESCRIPTION
Flat Plate Solar Collectors	$5852.76	Minor Construction
ASR 33 Teletype	$1285.00	Computer System
Plenum Heat Exchanger and Booster	$1150.00	Other, FJSRL Equipment Item
Valve (Single)	$ 57.12	Minor Construction
Valve Motor	$ 135.58	Minor Construction
Valve Linkage	$ 32.03	Minor Construction
TOTAL	$8512.03	

Summary

Minor Construction	$6077.49
Computer System	$1285.00
Program Operation	N/A
Other Equipment	$1150.00
TOTAL	$8512.49 (Check)

Solar Heating Retrofit of Military Family Housing
AFA 141-5/FJSRL JON 7903-03-75
June 1975

ITEM	COST	WORK DESCRIPTION
Gas Meters	$471.88	Program Operation
Plate Coil Heat Exchangers	$992.96	Minor Construction
40 Amp Switches	$ 60.00	Computer System
Integrated Circuit (SN74141N)	$ 30.25	Computer System
Integrated Circuit (SN74153N)	$ 16.50	Computer System
Integrated Circuit (SN74175)	$ 26.45	Computer System
Microcircuit (UA74175)	$ 57.00	Computer System
Integrated Circuit (SN7400N)	$ 12.40	Computer System
Integrated Circuit (SN7438N)	$ 6.50	Computer System
Integrated Circuit (SN7442N)	$ 5.25	Computer System
Light Emitting Diodes	$ 21.00	Computer System
Hex Buffer Switch, Clock	$ 12.00	Computer System
Hex Buffer Clock	$ 12.00	Computer System
Integrated Circuit (SN7474N)	$ 3.75	Computer System
Annubar Sensor	$ 34.24	Program Operation
Annubar Sensors	$176.65	Program Operation
Valve (Single)	$ 54.40	Minor Construction
Valve (3 Way)	$ 66.92	Minor Construction
Valve Motor	$135.58	Minor Construction
Valve Motor	$116.90	Minor Construction
Valve Linkage	$ 61.02	Minor Construction
Valve Linkage	$ 30.51	Minor Construction
Sockets	$ 94.00	Computer System
Terminal Blocks	$ 30.33	Computer System
Integrated Circuit (SN7404N)	$ 4.00	Computer System
Integrated Circuit (SN74132N)	$ 12.30	Computer System
Integrated Circuit (SN74163N)	$ 8.30	Computer System
Clock Chips	$ 25.60	Computer System
Integrated Circuit (Analog Multiplex)	$116.90	Computer System
TOTAL	$2695.67	

Summary

Minor Construction	$1458.29
Computer System	554.61
Program Operation	682.77
Other/Equipment	N/A
TOTAL	$2695.67 (Check)

Solar Heating Retrofit of Military Family Housing
AFA 141-5/FJSRL JON 7903-03-75
July 1975

ITEM	COST	WORK DESCRIPTION
Itel 8 Mod 80 Microprocessor with 7 I/O Cards	$4647.00	Computer System
Domestic Hot Water Preheat Coil	$ 313.51	Minor Construction
Modular Power Supply (5V)	$ 128.40	Computer System
Kynor Wire Wrap	$ 32.52	Computer System
Teflon Coated Wire	$ 606.00	Computer System
Nylon Coated Wire	$ 240.00	Computer System
Scotchflex Connector (14-SK)	$ 98.00	Computer System
Microprocessor Relay Rack	$ 261.08	Computer System
AC-DC Converter	$ 189.39	Computer System
Integrated Circuit (Analog Multiplex)	$ 50.10	Computer System
Scotchflex Connector (16-WR)	$ 32.87	Computer System
Scotchflex Connector (14-WR)	$ 28.76	Computer System
Scotchflex Connector (16-SK)	$ 119.00	Computer System
RG58U Coaxial Cable	$ 540.00	Minor Construction
Spectral Pyranometer	$1059.39	Other,FJSRL Equipment
Integrated Circuit (SN7476N)	$ 3.90	Computer System
Integrated Circuit (SN74128N)	$ 4.00	Computer System
LED Display Numeric Indicator	$ 40.10	Computer System
Integrated Circuit (Analog Multiplex)	$ 41.10	Computer System
100 Pin Sockets (Wire Wrap)	$ 34.60	Computer System
40 Pin Sockets (Wire Wrap)	$ 44.40	Computer System
Terminal Blocks	$ 53.92	Computer System
BCE Reimbursable Work Order	$ 265.73	Minor Construction
TOTAL	$9037.22	

Summary

Minor Construction	$1119.24
Computer System	6858.59
Progeam Operation	N/A
Other/Equipment	1059.39
TOTAL	$9037.22 (Check)

Solar Heating Retrofit of Military Family Housing
AFA 141-5/FJSRL JON 7903-03-75
August 1975

ITEM	COST	WORK DESCRIPTION
1702 Memory Chips	$762.50	Computer System
Dry Temperature Sensors	$662.20	Computer System
14 Pin Wire Wrap Sockets	$ 83.00	Computer System
40 Amp Switch	$ 12.00	Minor Construction
Pressure Sensor	$160.50	Program Operation
Pressure Sensors	$481.50	Program Operation
Teletype Paper Tape	$ 94.40	Program Operation
Integrated Circuit (SN825123)	$ 33.84	Computer System
40 Pin Scotchflex Header	$122.10	Computer System
40 Pin Scotchflex Header	$146.40	Computer System
Bi Polar Priority Encoding Chip	$ 15.00	Computer System
Bi Polar Eight Bit I/O Port	$ 18.40	Computer System
Voltage Regulator	$ 16.25	Computer System
Integrated Circuit (SN825123)	$ 65.35	Computer System
BCE Reimbursable Work Order	$112.75	Minor Construction

TOTAL $2786.19

Summary

Minor Construction	$ 124.75
Computer System	1925.04
Program Operation	736.40
Other/Equipment	N/A
TOTAL	$2786.19 (Check)

Solar Heating Retrofit of Military Family Housing
AFA 141-5/FJSRL JON 7903-03-75
September 1975

ITEM	COST	WORK DESCRIPTION
Contract Construction	$30,533.39	Minor Construction
BCE Reimbursable Work Order	$ 1,915.16	Minor Construction
Power Supply Units (28V)	$ 130.45	Computer System
Teletype Paper	$ 49.35	Program Operation
Rack Mounted Panel	$ 46.12	Program Operation
Pyranometer Mount	$ 311.80	Program Operation
Display Panel	$ 110.64	Program Operation
Aluminum Chassis	$ 121.58	Program Operation
Digital Encoder Chip	$ 14.07	Computer System
Solid State Relays	$ 132.44	Computer System
TMQ-15 Weather Tower*	$2,909.00	Other, 12th Weather
TMQ-20 Weather Tower*	$4,440.00	Squadron Equipment
TOTAL	$40,714.00	

Summary

Minor Construction	$32,448.55	
Computer System	276.96	
Program Operation	639.49	
Other/Equipment	7,349.00	
TOTAL	$40,714.00	(Check)

* Costs of tactical weather towers ($7349) not charged against the project orders.

Solar Heating Retrofit of Military Family Housing
AFA 141-5/FJSRL JON 7903-03-75
October 1975

ITEM	COST	WORK DESCRIPTION
Digital Encoder Chips (SN74148N)	$ 18.46	Computer System
Tarps	$149.54	Program Operation
Pushbutton Electric Switches	$ 40.20	Computer System
BCE Reimbursable Work Order	$214.75	Minor Construction
TOTAL	$422.95	

Summary

Minor Construction	$214.75
Computer System	58.66
Program Operation	149.54
Other/Equipment	N/A
TOTAL	$422.95 (Check)

Solar Heating Retrofit of Military Family Housing
AFA 141-5/FJSRL JON 7903-03-75
November 1975

ITEM	COST	WORK DESCRIPTION
Watt Hour Meters	$ 6.00	Program Operation
Valves (Single) and Fittings	$ 34.30	Program Operation
50 Psi Pressure Relief Valves	$ 21.50	Program Operation
Sockets for Watt-Hour Meters	$ 49.89	Program Operation
BCE Reimbursable Work Order	$572.60	Minor Construction
Electroplating Kit	$ 34.94	Program Operation
Weather Tower Fitting	$ 0.97	Program Operation
TOTAL	$720.20	

Summary

Minor Construction	$572.60
Computer System	N/A
Program Operation	147.60
Other/Equipment	N/A
TOTAL	$720.20 (Check)

Solar Heating Retrofit of Military Family Housing
AFA 141-5/FJSRL JON 7903-03-75
December 1975

ITEM	COST	WORK DESCRIPTION
Teletype Roll Paper	$ 84.60	Program Operation
BCE Reimbursable Work Order	$382.68	Minor Construction

TOTAL $467.28

Summary

Minor Construction	$382.68
Computer System	N/A
Program Operation	84.60
Other/Equipment	N/A
TOTAL	$467.28 (Check)

Solar Heating Retrofit of Military Family Housing
AFA 141-5/FJSRL JON 7903-03-75
January 1976

ITEM	COST	WORK DESCRIPTION
Plumbing Line Adapters	$ 7.40	Program Operation
Valves	$20.80	Program Operation
Nipple	$ 0.40	Program Operation
Dielectric Union	$ 4.80	Program Operation
Elbows	$ 2.30	Program Operation
Computer Crystals	$31.72	Computer System
Teletype Punch Paper	$63.00	Program Operation
BCE Reimbursable Work Order	$51.83	Minor Construction
TOTAL	$182.25	

Summary

Minor Construction	$ 51.83
Computer System	31.72
Program Operation	98.70
Other/Equipment	N/A
TOTAL	$182.25 (Check)

Solar Heating Retrofit of Military Family Housing
AFA 141-5/FJSRL JON 7903-03-75

GRAND SUMMARY

Minor Construction	$42,450.18
Computer System	10,990.58
Program Operation	2,539.10
Other/Equipment	9,558.39
TOTAL	$65,538.25

Minus tactical weather tower cost of $7,349 not charged against the Project Orders.

GRAND TOTAL $58,189.25